ISBN 0-7729-2506-2

1985 BACTERIOLOGICAL WATER QUALITY AT KINGSTON, LAKE ONTARIO

MAY, 1987

Ministry of the Environment
Ontario

J. Bishop, Director
Water Resources Branch

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1.0 SUMMARY AND CONCLUSIONS

The results of this study have provided a comprehensive synoptic overview of the extent and location of bacteriological contamination of the lake and inner harbour waters fronting the city of Kingston during 1985. However, this survey was not conducted under overflow conditions, for which it is believed that at least 25 mm of rain is required. Wet weather conditions investigated were associated with rainfalls of 6 to 12 mm in 24 hours, and thus do not represent true bypass conditions. Nevertheless, specific areas have been identified requiring further attention.

1. In 1985, the Kingston waterfront showed generally good bacteriological water quality with the exception of a few localized nearshore areas where fecal coliform levels exceeded MOE objectives. These investigations showed that bacterial plumes largely hug the shore or become trapped in slips or embayments, and do not generally extend very far into Lake Ontario or the Cataraqui River.

2. Most of the city sewers were either stagnant or flowed only very slowly under dry weather conditions. Exceptions were sewers at Dufferin St. and Bell Park Drive. The Dufferin St. sewer impacts directly upon the Cataraqui River; although a relation was not established for Bell Park Drive, it was not ruled out either.

3. Under dry weather, bacterial levels exceeded 100 fecal coliforms (FC)/100 mL at several locations along the waterfront. These included the Cataraqui River near Dufferin St., Anglin Bay, the downtown waterfront area, the lakeshore east and west of Richardson's Beach, Portsmouth Harbour, and the north end of Lake Ontario Park.

4. Under wet weather conditions (up to 12mm rainfall), the areas of bacterial impairment were not significantly greater than those observed under dry weather conditions. The worst extent of contamination was found to occur in the Cataraqui River adjacent to the Dufferin St. storm sewer outfalls, where counts were as

high as 72,000 organisms/100 mL on one survey date soon after rainfall. Samples taken from the Dufferin St. storm sewer indicated maximum fecal coliform levels above 10^6 organisms/100 mL during runoff events in two separate occasions.

5. Both MOE and Health Unit data indicated that Richardson's Beach is the most bacteriologically polluted recreational site in the Kingston area. The July 16 - August 30 geometric mean at this site was 83 FC/100 mL; 40% of daily 5-sample geometric means exceeded the Provincial Water Quality Objective of 100 FC/100 mL for body contact recreation. The Collingwood St. wind surfing site, Lake Ontario Park buoys area, Olympic Harbour piers area and West St. sailing club also exceeded objectives more than 20% of the time according to Health Unit data; MOE data also indicated high bacterial counts at these sites.

6. Health Unit results show that less difference occurred between wet and dry conditions in 1985 (a relatively dry year) than in either 1984 or 1986 (wetter years). However, similar areas exhibited the highest bacterial counts in all three years, suggesting that the main problem areas are the same in each year.

7. A dye study conducted by the City of Kingston indicated that illegal sanitary input from the King St. W. golf course was discharging through the Lake Ontario Park storm sewer, and impacting on Lake Ontario Park beach. This source of contamination has since been eliminated.

8. At nearly all storm sewers sampled, E. coli accounted for over 75% of the fecal coliforms present. This suggested that the sources are largely related to human and/or animal fecal wastes.

2.0 RECOMMENDATIONS

1. The City of Kingston should undertake a pollution control planning study. This study would include all pollution sources within their jurisdiction. It would help to better define the sewer loadings during wet and dry weather conditions, and to identify which sewers are impinging upon the recreational beaches.

2. Appropriate abatement strategies should be developed and implemented by the City of Kingston to address the fecal contamination problems as identified at the following areas: Richardson Beach, Olympic Harbour, Collingwood Street wind surfing site and West Street, as well as the following sewers: Dufferin St. sewers to the inner harbour, and the lakefront sewers between the PUC dock and West Street.

3. After abatement measures have been implemented, additional surveillance should be undertaken by the Water Resources Branch, in co-operation with the Southeastern Region, to assess the effectiveness of remedial measures. Data so generated should be integrated with the results of the ongoing Health Unit monitoring.

3.0 INTRODUCTION

The Kingston Harbour area, including the lower Cataraqui River and the adjacent Lake Ontario shoreline, is extensively used for recreational purposes, including swimming and boating. For a number of years, several bathing beaches have been closed regularly due to bacteriological contamination. Generally, the beaches are posted following rainfall until sampling by the Kingston, Frontenac and Lennox and Addington (K, F, L & A) Health Unit indicates that fecal coliform counts have decreased below 100 organisms/100 mL. The Kingston area has been identified on a regional beaches action plan by the Southeastern Region of the Ministry of the Environment as an area requiring urgent attention.

The City of Kingston is situated at the mouth of the Cataraqui River, which empties into Lake Ontario at the point where the latter flows into the St. Lawrence River (Figure 1). The Cataraqui River represents the southern end of the Rideau Canal system joining Lake Ontario to the Ottawa River. In addition, Kingston is located at the western end of the Thousand Islands, which stretch eastward for about 60 km in the international section of the St. Lawrence River. Consequently, the area is very popular for water-related activities such as swimming, sailing, wind surfing and fishing. Kingston Inner Harbour is considered to be the area of the lower Cataraqui River north of the Highway 2 causeway, while Kingston Outer Harbour is the river mouth and lake area south of the causeway.

The older portion of the City of Kingston is served with large numbers of storm and combined sewer outfalls, which mainly discharge to the waterfront areas. A few storm sewers also drain to the Little Cataraqui Creek in the west end of the city (Figure 1). The sewers draining the older portions of the city contain numerous crossovers and interconnections, and hence considerable potential for discharge of highly contaminated waste to the waterfront. Most of the overflow is routed through a system of interceptor sewers to the River St. pumping station in the east end of the City, from which sewage is pumped under

the Cataraqui River to the Kingston STP, located about 5 km east of the City. This pumping station has a capacity of approximately 90 x $10^3 m^3/d$ (20 MGD). Overflow from the River St. pumping station is discharged to the Cataraqui River at a point approximately in mid-river in the Inner Harbour area.

Circulation in the inner harbour has been studied using oranges as markers (MOE, 1981). Under southwest wind conditions, it was found that surface currents move upstream from the Highway 2 causeway to Bell Island. These surface currents are influenced by both the winds and the northeastward Lake Ontario surface flow. Although not explicity mentioned, the return (downstream) flow is presumably found below the surface in the dredged boating channel near the east shore.

Several studies since 1975 (e.g. Stagg, 1975; MOE, 1981, 1982) have addressed bacteriological pollution in Kingston. In 1975 (Stagg, 1975) the geometric mean of fecal coliform counts exceeded the Provincial Water Quality Objective of 100 organisms/100 mL at three sites: the downtown waterfront, foot of Collingwood St., and Portsmouth Harbour. However, the report concluded that the water quality was "acceptable" in Kingston's swimming areas.

Following closing in 1979 of several beaches, the Ministry conducted limited studies of the Cataraqui River under the Experience '81 and '82 programs (MOE, 1981, 1982). In May 1981, after a 60 mm rainfall, three areas with fecal coliform (FC) counts > 100 organisms/100 mL were found in the Cataraqui River: about 1 km south of Highway 401, near Bell Island and just north of the Highway 2 causeway. Four days later, fecal coliform counts had returned to acceptable levels. Shoreline samples also exceeded 100 FC/100 mL on several occasions at points such as Bell Island, Knapp's Marina and the Rideau St. storm sewer. These exceedences were not always attributed to rainfall-associated runoff, and thus indicate intermittent inputs such as wildlife, or that the fecal coliforms may have been species other than _E. coli_. However, studies in 1982 (MOE, 1982) showed that _E. coli_ predominated over other species such as _Klebsiella_

or Enterobacter; these studies also showed that contaminated sediment did not appear to be a bacterial source (average E. coli counts were 17/100 mL, and maximum was 40/100 mL).

In addition to the above, data collected at the various beaches by the Health Unit has indicated frequent occurrences of FC > 100 organisms/100 mL, and has led to several beach postings in recent years. Locations of beaches monitored by the Health Unit are shown in Figure 1A. Health Unit data are discussed in this report in support of Ministry surveys where applicable.
In response to the concerns raised in the Ministry's Beaches Action Plan, the Southeastern Region requested that the Great Lakes Section perform a bacteriological survey similar in scope to that performed in 1984-85 in Belleville (Poulton, 1986). The purposes of the present survey included an attempt to provide detailed information on bacterial loadings from the Kingston Waterfront storm and combined sewer overflows, along with coincident receiving water bacteriological data; an assessment of the effect of rainfall on the various inputs and receiving waters; an assessment of possible sources of bacterial contamination affecting Kingston Waterfront beaches; and an estimate of the magnitude of "first-flush" inputs to the harbour of stagnant water lying in the storm sewers between rainfalls.

4.0 SURVEY DESIGN

The grid of sampling stations was designed to provide coverage of the Cataraqui River and nearshore Lake Ontario within Kingston city limits, including all storm and combined sewer outfalls that might conceivably be contributing to this area, but not including several sewers draining to the Little Cataraqui Creek. Six additional stations were located in the St. Lawrence River within 2 km east of the mouth of the Cataraqui River, in order to trace possible downstream movement of contaminated water on either side of Cedar Island. As the resultant sampling grid was too large to provide adequate coverage during any one survey day, the grid was divided into two subgrids. Figures 2 and 3 show the sampling locations in each subgrid. The area of Kingston Outer Harbour extending about 1 km south of the Highway 2 Causeway was included in both subgrids, in order to provide data continuity between the two areas, as well as collection of an adequate amount of data in the downtown central waterfront area.

To ensure that all potential stormwater sources would be included, City of Kingston sewer plans plus a sewer survey questionnaire (J. Bishop, MOE Southeastern Region), were consulted. A few very small sewers were not included in this study; the remainder (plus the mouth of the Little Cataraqui Creek) were included in the survey. A brief description of each sewer (including sewer numbers designated by the City) is given in Table 1, and the locations are shown in Figures 2 and 3. As nearly all these inputs are via submerged pipes, sampling via manhole was performed, by lowering bacti bottles from the manhole. Qualitative estimates of flow rates were attempted by visual observation at the surface.

Except for use of two subgrids, the survey procedures followed were similar to those used during 1985 in Belleville (Poulton, 1986). Both wet and dry weather surveys were conducted. Survey dates, including the rainfall as measured at Kingston Airport, are given in Table 2. This also indicates where duplicate

samples were collected. These duplicates were obtained when laboratory loads permitted, in order to provide adequate data for the determination of geometric means with a reasonable degree of confidence. As most pairs of receiving water samples collected in July showed low between-sample variations, it was decided to collect single samples from both subgrids during an August wet weather event, in order to provide an estimate of overall impacts. All samples were analyzed for fecal coliform and fecal streptococcus. One sample of each duplicate pair and all single samples were analyzed for E. coli. All analyses were performed at the mobile bacteriological laboratory, which was parked on the Kingston water works property. This permitted the rapid completion of all analyses.

4.1 Sequential Sampling:

To provide an estimate of bacterial loadings in the Bell Island area during wet weather, a sequential sampling survey was performed on August 13-16, 1985. At the start of a rainfall event, samples were collected at a rate of 2 to 4 per hour from the Dufferin Street (05-64) and Bell Park Drive (05-66) storm sewers (Figure 2). Hourly sampling was also conducted at the Bell Island beach location (2834). On the days following rainfall (August 14 and 16), only the beach locations were sampled sequentially; duplicate samples were taken from each source location at the start of each survey day. Sampling was performed for 2 to 6 hours on each day.

A planned sequential wet weather survey for Richardson Beach and Lake Ontario Beach in subgrid 2 had to be cancelled due to lack of rainfall while field and lab crews were available.

5.0 RESULTS

5.1 Dry Weather Surveys

For each subgrid, three days' worth of sewer data and two days' worth of receiving water data were obtained (Table 2). Figures 4-9 present data for fecal coliforms (FC) and *E. coli* (EC) in the inner harbour, downtown waterfront and Lake Ontario waterfront areas respectively. The downtown waterfront data (Figures 6-7) includes the area common to both subgrids; receiving water data are for the two days of greatest bacterial contamination (July 22 and 23). FC results are mainly geometric means of duplicate samples; EC data are single samples.

5.1.1 Sewers

Many of the sewers were either completely dry or contained such a small amount of water that it was impossible to collect a sample; these sewers are indicated on Table 1 and shown on Figures 2 and 3 only. Most of the other sewers contained only small amounts of water which was either stagnant or being maintained at lake level by oscillating seiche-like flows. Thus, bacterial counts represented more a potential for first-flush contamination at the beginning of runoff, as opposed to actual dry-weather loadings.

The only locations with significant dry weather flow were the twin manholes at the foot of Dufferin St. (MOE stations 05-63, 05-64) and the Bell Park Drive storm sewer (05-66). It was not possible to obtain flow rates for these sewers; however, Bell Park Drive appeared to have the most flow. On July 24, an oily smell was detected at this sewer, and a count of 3×10^6 FC/100 mL was obtained. City of Kingston sewer plans indicate possible interconnections with the sanitary system at both the above-noted locations, as well as numerous others. It should also be noted that the City was undertaking sewer separation in the headwaters of the Dufferin St. sewer catchment in 1985. The influence of these sewers on the receiving waters is discussed below.

A backup of sanitary sewage at Princess St. (location 07-07) was reported immediately prior to the July 22 sample, during a period of construction. The presence of sanitary sewage was reflected by the results (9.5 and 12.3 x 10^6 FC/100 mL) on that day. This situation was rectified by July 24, when it was not possible to obtain a sample; however, on August 6, counts of 0.28 and 0.35 x 10^6 FC/100 mL were again obtained, suggesting further sanitary inputs. This location yielded the highest dry-weather bacterial counts of any downtown sewer during the survey.

5.1.2 Receiving Water

Areas in which bacterial counts exceed 100 FC/100 mL (on the basis of two-sample geometric means) have been indicated in Figures 4, 6 and 8. It was found that during dry weather, areas of bacteriological impairment exist in the downtown waterfront area, along Richardson Beach (extending to the east), Portsmouth Harbour, Lake Ontario Park, and in the inner harbour near Dufferin St. and Anglin Bay.

The zone in the downtown waterfront area in which FC > 100/100 mL varied considerably in extent and location from one day to another. Areas impacted by all storm sewers in the downtown waterfront showed FC > 100/100 mL at some time during the five days; the highest FC level occurred sporadically at different locations. The highest level (10.7 x 10^6 FC/100 mL) occurred at station 07-07. The zone of pollution was largest on July 22, when it extended to mid-river (Figure 6). This may be attributed to input from the construction related backup of sanitary sewage at the foot of Princess St. (mentioned above). However, other sources may have been involved. These are difficult to pinpoint in an area such as this where a large amount of recreational boating occurs. This is probably also true of the impairment at Portsmouth Harbour, a heavily used area where a large breakwall limits the exchange of water with the lake (maximum daily FC was 150/100 mL).

In the MacDonald Park area (near Richardson Beach), dry weather contamination of nearshore waters (FC > 100 organisms/100 mL) occurred on both July 23 and August 6, with an apparent eastward plume evident on July 23 (Figure 8). A dye test performed by the Health Unit failed to locate a source of this contamination.

In the vicinity of the north end of Lake Ontario Beach, the fecal coliform count exceeded 100 organisms/100 mL on August 6. This was also an area of wet weather impairment discussed in section 5.2.2.

Within the inner harbour area, elevated bacterial levels were found in Anglin Bay and at the foot of Dufferin St. Anglin Bay receives two storm sewers with daily FC counts as high as 82000/100 mL, but with apparently very little flow. This is an area of considerable construction activity at the time of the survey, and also limited exchange with open water areas.

At Dufferin St., two sewers with bacterial counts ranging from 139 to 620 FC/100 mL and a significant flow empty into the harbour. These sewers (mentioned in section 5.1.1) apparently contribute to elevated bacterial counts in this area (Figure 4). However, the apparent loading of these sewers is not as great as that of the Bell Park Sewer (05-66; section 5.1.1), where a count of 3×10^6 FC/100 mL was observed on July 24. The receiving water in the latter area did not show an increased bacterial count on that day, but on July 22, it did show a fecal coliform count of 54 organisms/100 mL (44 E. coli/100 ml). However, this sampling point is about 500 m from the outfall in a marshy area which is overgrown with aquatic plants in summer, thus representing an area in which water would probably move slowly, with plenty of time for bacteria to die off on most occasions. That no sewer sample was obtained on July 22 also suggests the possibility of intermittent inputs at this source. This area was also noted to exhibit occasional high bacteriological results during a 1984 survey (MOE, unpublished data). In that year, five-day geometric means were 120 FC/100 mL at a station similar to that used in 1985, and 442 FC/100 mL at a location midway up the inlet towards the sewers.

The Aquatic Ecosystems Objectives Committee in 1983 recommended to the Science Advisory Board of the International Joint Commission that the E. coli geometric mean level in receiving waters should not exceed 23 organisms/100 mL for protection of human recreational users of nearshore waters from increased gastrointestinal illness. Areas where the single sample E. coli count exceeded 23 organisms/100 mL are shown in Figures 5, 7 and 9. Although this is not a strictly true comparison as it is based on single samples, it should be noted that the indicated zones are larger than the zone based upon 100 FC/100 mL, especially in the vicinity of Richardson Beach and the downtown waterfront. This is not surprising as E. coli accounts for over 75% of the fecal coliforms at nearly all sewer locations sampled (Figures 4-9).

5.2 Wet Weather Surveys

In no cases during the survey was a heavy storm observed. Rainfalls are given in Table 2. These were all short duration events with relatively low total rainfall (maximum daily rainfall was 12.4 mm).

5.2.1 Sewers

Sequential sampling of the Dufferin Street sewer (05-64) and the Bell Park Drive sewer (05-66) was conducted during rainfalls which occurred in the evening of August 13 and the morning and afternoon of August 15. These rainfalls were all of the brief-duration, geographically spotty nature which is very typical of rainfalls occurring during hot, humid summer weather. The rainfall data in Table 2 was collected at the Kingston airport west of the city and may not have represented the actual rainfall at the survey site.

Fecal coliform results for the two sewers and the Bell Island beach location are given in Table 3. Although the data were irregular, some evidence of peak bacterial concentrations early in the event were noticed for most rainfall events. Although loadings could not be determined, an impact of the Dufferin Street sewer on the receiving water was observed and is

discussed below in section 5.2.2. No impact of the Bell Park Drive sewer was observed at this time, possibly due to the distance of the sewer outfall from the receiving water sampling point as discussed in section 5.1.2.

Except at Bell Park on August 14, bacterial counts observed on the day after rainfall had generally decreased to values similar to those observed in the dry weather surveys; however, the Bell Park sewer did exhibit extremely variable dry weather bacterial counts in the July dry weather sampling (Figure 4; section 5.1.1.).

5.2.2 Receiving Water

Zones in which the single sample fecal coliform counts exceeded 100 organisms/100 mL during or after wet weather are shown in Figures 10-17. It should be emphasized that the Provincial Water Quality Objective of 100 FC/100 mL should be applied to the geometric mean of a series of samples only and that the above figures merely depict single sample levels as a means of illustrating zones of potential impairment. During August, it was decided to discontinue the procedure used in July of taking duplicate samples at each location in one subgrid, in order to obtain some measure of contaminated zones over the entire waterfront in rainfall periods, which were very infrequent during the summer of 1985.

For the most part, zones of excessive bacterial contamination in wet weather were not larger than those observed under dry weather conditions (Figures 4-9). The major exception is the west shore of the inner harbour extending southward from Dufferin Street towards Anglin Bay as discussed below. No areas with FC >100 organisms/100 mL were observed on August 9 (subgrid 1) and August 17 (subgrid 2 only, no figures were included for these two instances); these represent conditions two days after rainfall.

The highest fecal coliform level observed during wet weather was in the Cataraqui River (inner harbour) adjacent to the storm outfalls at the foot of Dufferin St (sewers #05-63 and 05-64). The counts at this location always exceed 1000 organisms/100 mL,

and were as high as 72,000 organisms/100 mL on August 15. This contamination was localized on most days, although it appeared to spread southward on August 8 (Figure 10). Samples taken from the Dufferin St. storm sewer which discharges to this area indicated maximum fecal coliform levels above 10^6 organisms/100 mL during runoff events on August 13 and 15 (Section 5.2.1; Table 3). This is the location of sewer separation activity during 1985, mentioned earlier.

According to the Ministry's survey results, under runoff conditions, fecal coliform counts at Bell Island beach reached peak levels of 250 and 330 organisms/100 mL; however, these decreased rapidly in less than 1 hour, and most readings taken by the end of the sampling period were below 20 FC/100 mL; on August 14, the levels ranged from <4 to 60 FC/100 mL (Table 3). The short duration of contamination was a function of the particular storm event monitored, and does not necessarily reflect average storm conditions at that site. It should be noted that Health Unit data in 1985 (Table 4) indicated this location to be quite clean, with a geometric mean of 24 FC/100 mL and only 17% of samples being above 100 FC/100 mL. On August 17, fecal coliform counts at two points in the Cataraqui River immediately upstream of Bell Island were above 100 organisms/100 mL (Figure 17). It appears that this contamination was intermittent and of little consequence, since it occurred on only one occasion.

In Anglin Bay, fecal coliform counts ranged from 160 to 1130 organisms/100 mL under runoff conditions. Input from the two storm sewers entering this area, plus the impact of construction activities, may have been responsible; however, no wet weather bacterial loadings were obtained. The zone of pollution seemed to be confined to the bay area, but on some occasions may have been responsible for elevated FC levels downstream as observed in Figures 11 and 15.

In the downtown waterfront area, zones of elevated bacterial levels were similar to those observed in dry weather, with considerable day-to-day variation in location and size of those zones. Average bacterial levels were also similar, suggesting

that inputs to this area are relatively independent of weather conditions, i.e. that very little if any stormwater runoff from the area sewers is contributing. The only exception was one sample (>3640 FC/100 mL) in a slip area adjacent to the Princess St. sewer and the Wolfe Island ferry docks on August 15 (Figure 13). The E. coli count (2540/100 mL) and FC/FS ratio (>21), plus the fact that this sample was taken soon after a rainfall, were highly suggestive of a runoff-related fecal input to this area. This result also suggests that samples should be obtained within several hours after rainfall, to provide indications of inputs before the contaminated water is mixed and transported away. Along the lakefront west of downtown, two areas of bacterial contamination appeared on August 14 (Figure 12). These were near West St., and in the Collingwood St. area, both of which receive several sewer inputs. Overall, the water quality of the river and lakefront receiving waters is quite good; the extent of lakefront contamination was generally quite small in spatial and temporal extent.

At Lake Ontario Park, bacterial contamination was observed adjacent to the storm sewer in the north end, with bacterial counts as high as 620 FC/100 mL and 620 E. coli /100 mL on August 15. Subsequent to the survey, a dye test (City of Kingston, unpublished) disclosed sanitary input to this location originating from the golf course located north of King St. W. in this area. This source of sanitary sewage input has since been eliminated.

During and following wet weather (August 14-17), fecal coliform counts immediately downstream of the dock at Kingston Mills (upstream on Cataraqui River; not shown in the figures) exceeded 100 organisms/100 mL, with a 4-day geometric mean of 210 organisms/100 mL. This contamination appeared to be localized, since fecal coliforms between this point and the area north of Bell Island were generally very low.

5.3 Health Unit Data

Fecal coliform data for the various beach locations sampled between 1983 and 1986 by the K, F, L & A Health Unit are presented in this section, in order to provide a comparison between data obtained from another source, as well as a comparison between 1985 and other recent years. In order to provide an estimate of the impact of wet weather on bacterial contamination, these data were grouped according to wet and dry weather conditions. Wet weather conditions were assumed if at least 2 mm of rain was recorded within a one-day period prior to sampling (Atmospheric Environment Service data at Kingston Airport); all others were assumed to be dry weather conditions. These two groups of data (log daily geometric means) were compared by t-test. The results, along with the annual "wet" and "dry" geometric means, are given in Table 4.

The results show that, during 1983, 1984 and 1986, most of the locations sampled show significantly higher bacterial counts under wet weather conditions. These include several locations (1983 and 1986) which exhibited large differences (factor of 3) in geometric means but large day-to-day variation; although these were not significant at the usual $P < 0.05$ level, they were significant at $P < 0.10$. By contrast, in 1985 only two locations (Collingwood St. windsurfing and West St. sailing) exhibited significant differences. A comparison of rainfall levels considering only those events included in the sampling program showed that 74, 241, 183 and 263 mm of rain fell in 1983, 1984, 1985 and 1986, respectively. It appears that the higher amounts of rainfall recorded in 1984 and 1986 relative to 1985 could partly explain the fewer number of significant differences found in 1985; however, this does not account for the 1983 result. However, additional factors may be important, including the on-going program of sewer separation, as well as other meteorological variables such as the duration and intensity of rainfall, winds (reflected in currents and wave-induced resuspension), etc. A complete analysis of causative factors is beyond the scope of this report.

The 1985 data were ranked according to geometric mean fecal coliform counts in Tables 5 and 6. Due to station location changes in mid-July 1985 (wading in to a greater water depth), only data collected after July 15 were used. Furthermore, the number of dates sampled varied considerably with location. In Table 5, all locations are ranked based on six common sampling dates, while in Table 6, only those locations sampled on at least 17 dates are included; the latter represent the best estimate of average fecal coliform levels over the July 16 - August 30 period. Included in this table are the percentages of daily geometric means (usually 5 samples/day) which exceeded the Provincial Water Quality Objective of 100 FC/100 mL based on the geometric mean of a series of samples (MOE, 1978).

Both data sets indicate that Richardson's Beach is the most highly bacteriologically polluted beach in the Kingston area, with a geometric mean of 83 FC/100 mL for the July 16 - August 30 period. The daily geometric mean exceeded the MOE Objective of 100 FC/100 mL on 40% of the sampling dates. This beach is located in an area shown to have bacterial counts above 100 FC/100 mL during Ministry dry weather survey on August 6 (Figure 8). The beach area did not seem to be affected during a wet weather survey, although nearby waters showed FC > 100/100 mL (August 14; Figure 12). It is probable that differences between MOE and Health Unit results may arise from factors such as different sampling methods (boat vs. shore) and different sampling times. Under the higher rainfall conditions which occurred in 1986, this beach again had the highest FC counts, both for wet and dry conditions (Table 4).

Other areas which continually had high bacterial counts in the 1984-1986 period included Portsmouth (Olympic) Harbour, Collingwood St. wind surfing site and West St. (boat ramp and sailing sites). These areas were all shown to have high bacterial counts on one or more instances during the 1985 surveys. The fact that they are all high in these three years shows that the MOE data are representative of conditions occurring in different years, despite the fact that 1985 was an unusually dry year. The lack of significant differences between

wet and dry conditions in the 1985 beach data is in agreement with the general findings in the MOE survey of very little difference between wet and dry conditions.

The 1986 data (Table 4) show that the Lake Ontario Park areas have experienced considerably reduced levels of bacterial pollution. Daily geometric means at both the buoys and breakwater site exceeded the objective of 100 FC/100 mL only once (7% of the time), compared to 32% of the time at the buoys site and 13% of the time at the breakwater site in 1985. This is evidence of a positive result having occurred from the elimination of the sanitary input from the Cataraqui Golf & Country Club (section 5.2.2).

6.0 DISCUSSION

The results of the 1985 Kingston area bacteriological survey have shown that the lower Cataraqui River and Lake Ontario shoreline areas are affected by bacteriological inputs both under dry and wet weather conditions; in fact, for most of the shoreline the contamination is as great in extent under dry conditions as under wet conditions. Nearly all the older portion of the city is served by a complex network of storm and combined sewers which drain to the waterfront through submerged outfalls, that were in general found to be nearly dry or contain water at lake level under dry conditions. The lack of flow in these sewers suggests that dry weather flow is generally collected by the interceptor sewers which carry it to the River St. pumping station and thence to the Kingston STP; however, the existence of zones of dry weather bacterial degradation at locations such as Dufferin Street, Richardson Beach area, Portsmouth Harbour and the downtown waterfront (Princess St.) suggests that bacterial inputs to these areas which were not quantified in this study, occurred. It is likely that these areas have to be monitored further upstream in order to locate the sources.

Areas such as the downtown waterfront and Portsmouth Harbour which receive considerable non-contact recreational activity (sailing, wind surfing, etc.) present numerous opportunities for unquantifiable non-point source inputs, which cannot be realistically controlled in any remedial program. In addition, occasional accidental inputs such as the construction-related sanitary input at Princess St. will occur from time to time. Sewers discharging to these areas drain largely impervious urban areas (streets, parking lots, roof tops, etc.); consequently, they do not need a large rainfall to begin flowing and dry up rapidly after a storm. It is likely for this reason that the elevations in bacterial levels in downtown waterfront area were generally no worse under wet conditions than under dry conditions except for one area between Princess Street and the

Wolfe Island ferry docks, as mentioned in section 5.2.2. Any future survey designed to measure the impacts of wet weather on the waterfront area should account for this fact, by having samples collected as soon after the start of rainfall as possible.

Only at Dufferin Street and Bell Park Drive were significant dry weather flows noted. Such flows indicate the presence of groundwater recharge or infiltration to the sewers from porous soil layers, or the existence of sanitary inputs from illegal cross-connections or cooling water discharges. As discussed earlier, a definite impact on the Cataraqui River is observed at Dufferin Street, and a possible impact at Bell Park Drive; it is desirable to divert the entire portion of these flows to the River St. pumping station to reduce both dry and wet weather impacts.

Without a specialized effort, measurement of bacterial concentrations and loadings under runoff in a complicated, multi-source system is extremely difficult. In order to understand completely the dry-weather and runoff flows, and their impacts in the receiving water, mathematical modelling is almost essential. Several models are available for simulating flow hydrographs and pollutographs in storm sewers and receiving waters. Delleur and Dendrou (1980) discuss several which might be useful in the Kingston situation. Furthermore, it is desirable to concentrate sampling and modelling effort on a relatively small but impacted area of the waterfront, and studies should be undertaken in both dry and wet weather. Because of the impacts observed in 1985, and on water use patterns, Richardson's Beach area would be a logical site for such a study. The area from Bell Park Drive to Dufferin St. (and perhaps south to Anglin Bay) is another possibility, but does not receive the same heavy recreational usage as the Richardson's Beach area. Once a model is operating in a small sub-area, it should be possible to extend the model throughout the remainder of the waterfront area.

6.1 Fecal Coliform/Fecal Streptococcus Ratios

Fecal streptococcus results have generally been used in conjunction with fecal coliform data as an indication of the major source (human or animal) of bacterial contamination. However, studies in recent years have indicated that FC/FS ratios are not so easily interpreted. Results of an MOE-sponsored research study performed by Seyfried and Harris at the University of Toronto (TAWMS, 1985) have shown that non-human bacterial sources can have much higher FC/FS ratios than previously believed; indeed, dog, duck and gull fecal matter can have ratios (>10) similar to those of human fecal matter. Non-human sources were divided into three groups on the basis of FC/FS ratios (Table 7). In addition, FC/FS ratios can change rapidly with time and are generally useful only quite close to fecal pollution sources. Consequently, only sewer FC/FS ratios are discussed briefly with regard to these cautions.

FC/FS ratios based on single samples or 2-sample geometric means as appropriate are given in Table 8 for dry weather data. Locations suggestive of human or Type I animal input include 07-07 (Princess Street), 07-09 (Overflow chamber at Barrack Street) and 05-69 (Edson Street), however, it should be noted that the ratios were highly variable from day to day at all these locations; in addition, as water was generally stagnant or flowing only very slowly in these sewers, the time since input of the fecal material in unknown and hence the FC/FS ratios may have changed as a result of die-off and may thus be unreliable. Sewer #07-07 was the location of a construction-related backup of sanitary sewage already mentioned (Section 5.1.1). The FC/FS ratio of 13.7 on July 22 was in accordance with such a sanitary input; although the backup was corrected soon afterwards, the

FC/FS ratio of 11.6 on August 8 suggested further input from either humans or type I animals. Although the FC/FS ratios observed at sewers 05-64 and 05-66 during wet weather were generally indicative of mixed bacterial sources, occasional high values were observed (e.g. 448 and 31 at 05-66 on August 14). Overall, the FC/FS ratios observed during the time-sequential sampling were too variable to suggest a type of input.

Most of the other sewers exhibited highly variable FC/FS ratios indicative of mixed sources or of variable die-off rates since input. This situation is very similar to that observed in Belleville (Poulton, 1986). The three sewers draining to Cataraqui Bay (05-71, 05-47, 05-48) all exhibited FC/FS ratios below 0.5, suggesting predominantly non-human inputs to this area.

As a result of the problems associated with using FC/FS ratios as indicators of bacterial origins, a more specific indicator of human fecal contamination is needed. Preliminary results from an Experience '86 study (MOE 1986), suggest that _Clostridium perfringens_ may be useful as a specific indicator of some animal fecal wastes. _C. perfringens_ was recovered from cat and dog feces in the range of 1 to 2 million bacteria per gram (Table 9). In contrast, _C. perfringens_ was present at less that 140 cells per gram in a sample of human feces. Further studies on _C. perfringens_ would be useful to determine if this organism shows a correlation with urban stormwater runoff.

7.0 ACKNOWLEDGEMENTS

The author gratefully acknowledges the assistance of the following staff at MOE Southeastern Region for their assistance: Mr. G. Owen, Dr. A. Ley, Mr. J. Pruner, Mr. J. Bishop, Mr. M. German, Mr. D. Galloway, plus laboratory and field support staff. Thanks are also extended to Mr. M. Young, Ms. S. Janhurst and Mr. G. Horsnell and support staff of the Water Quality Section, Laboratory Services Branch for their assistance. The assistance of City of Kingston staff who provided sewer plans and assisted in the location and opening of sewer manholes is gratefully acknowledged. The assistance of the Kingston, Frontenac and Lennox and Addington Counties Health Unit, who provided important beach data, is gratefully acknowledged. Thanks are also extended to Ms. M. Griffiths, and Mr. Y. Hamdy of the Great Lakes Section for their helpful comments.

This project was partly funded by Environment Canada under the auspices of the Canada-Ontario Agreement.

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TABLE 1

KINGSTON HARBOUR BACTERIOLOGICAL SURVEY
STORM AND COMBINED SEWER SAMPLING STATION

STATION #	DESCRIPTION
05-55	Albert St. SS #10
07-02*	Albert St. CSO #11
05-51*	Alwington Beach SS #5
07-09	Barrack St. Overflow chamber CSO #27
07-10	Bay St. CSO #29
05-66	Bell Park Drive SS #35
05-52*	Beverley St. SS #7
05-53	Beverley St. SS #8
07-06*	Brock St. CSO #22
05-65*	Cataraqui St. SS #33
05-61	Clarence St. SS #21
05-54*	Collingwood St. SS #9
05-63	Dufferin St. SS #31
05-64	Dufferin St. SS #32
05-69	Edson St. SS #39
05-47	Elevator Bay SS #52
05-58	George St. SS #16
07-04*	Gore St. CSO #18
05-60	Johnson St. SS #20
05-72	King St. E. SS #28
05-48	L. Ontario Park SS #1
05-71	mouth of Little Cataraqui Creek
05-57*	Lower University SS #14
05-56*	MacDonald Park SS #12
07-01	Morton St. box sewer overflow #6
05-62*	North St. SS #30
07-03*	Okill Pumping Station Overflow #15
07-12*	Overflow chamber #4 overflow #36
05-49	Portsmouth Harbour SS and pumping stn. overflow #3
05-50*	Portsmouth Harbour SS #4
07-07	Princess St. interceptor and box sewer overflow #23
07-08*	Queen St. CSO #26
07-11	River St. pumping station overflow #34
05-68*	Shaw St. SS #38
05-70*	Sheppard St. SS #40
05-67	Weller Ave. SS #37
05-59*	West St. SS #17
07-05	William St. box sewer overflow #19

Note: Sewer numbers given under "Description" are those assigned by the City of Kingston.
* Dry locations from which no samples were obtained.

TABLE 2

SURVEY DATES
KINGSTON BACTERIOLOGICAL SURVEY, 1985

		Samples Per Station			
		Sewers		Receiving Water	
Date	Rainfall (mm) 24 hours	SG1	SG2	SG1	SG2
(a) Dry Weather (no rainfall for 6 or more days):					
July 22	nil	2		2	
July 23	nil		2		2
July 24	nil	1		2	
July 25	nil		1		
August 6	nil	2	2		2
(b) Wet Weather and days immediately following:					
August 8	12.4 (7th)			1-2	
August 9	nil			1-2	
August 13	6.6	*			
August 14	nil	*		1	1
August 15	8.0	*		1	1
August 16	nil			1	1
August 17	nil			1	1

Note * Sequential sampling of Dufferin St. and Bell Park Dr. sewers.

TABLE 3

FECAL COLIFORM COUNTS (ORG/100 mL) DURING SEQUENTIAL WET WEATHER SAMPLING (SEWERS AND BEACH), 1985

Date	Dufferin Street Sewer #32 (05-64)		Bell Park Drive Sewer #35 (05-66)		Bell Island Beach (2834)	
	Time	FC	Time	FC	Time	(duplicate) FC
August 13	20:35	3.8×10^6	20:30	2.0×10^4	20:45	230
	20:50	3.8×10^6	21:00	6.5×10^5	20:45	90
	21:05	2.6×10^6	21:30	1.21×10^6	21:45	40
	21:20	1.21×10^6			21:45	20
	31:35	0.60×10^6				
August 14	12:00	>3000	11:45	10.0×10^6	10:45	32; 40
	12:00	>3000	11:45	0.73×10^6	11:45	52; 20
					12:45	<4; 12
					13:45	60; 30
					14:45	20; 60
August 15	8:40	9.4×10^4	8:30	2.4×10^4	9:00	50; <5
	8:55	5.9×10^6	8:45	13.0×10^4	11:10	90; 100
	9:10	3.0×10^6	9:00	5.5×10^4	12:10	330; 250
	9:25	1.3×10^6	9:30	46.0×10^4	13:10	10; 10
	9:55	1.11×10^6	10:00	11.1×10^4		
	14:50	6.7×10^4	15:20	9.1×10^4		
	15:05	4.6×10^4	15:35	4.4×10^4		
	15:20	2.7×10^4	15:50	4.1×10^4		
	15:35	2.1×10^4	16:05	3.3×10^4		
			16:30	5.1×10^4		
			17:00	10.0×10^4		
August 16	7:20	3500	7:00	2300	6:15	2; <2
	7:20	3100	7:00	2400	7:15	4; <2
					8:15	2; <2
					9:15	2; 4
					10:15	2; 2
					11:15	20; 8
					12:15	14; <2
August 17					6:15	2; 18
					7:15	2; 4
					8:15	2; 2
					9:15	4; 10
					10:15	10; 2
					11:15	22; 10
					12:15	100; 12

TABLE 4

K, F, L & A HEALTH UNIT GEOMETRIC MEAN FECAL COLIFORM DATA

COMPARISON OF WET VS. DRY WEATHER

Location	Geometric Mean FC # / 100 mL.								t-test*			
	1983		1984		1985		1986		1983	1984	1985	1986
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry				
L. Ontario Park (buoys)	27	18	139	18	46	31	19	15	NS	0.01	NS	NS
L. Ontario Park (breakwater)	11	10	70	16	28	25	16	7	NS	0.05	NS	NS
Ontario Hospital	14	6	9	9	5	8	14	8	NS	NS	NS	NS
Olympic Harbour (breakwater)	-	-	15	9	125	21	13	7	-	NS	NS	NS
Olympic Harbour (piers)	167	49	860	64	17	55	341	39	0.10	0.01	NS	0.01
Alwington Place	21	15	149	19	30	34	27	34	NS	0.01	NS	NS
Collingwood St. (wind surfing)	-	-	-	-	121	18	115	67	-	-	0.01	NS
Richardson Beach	19	13	181	19	101	48	382	131	NS	0.01	NS	0.10
West St. (boat ramp)	134	50	340	41	65	38	301	28	0.10	0.01	NS	0.05
West St. (sailing)	35	11	218	9	69	23	206	44	0.05	0.01	0.01	0.05
Orchard St.	24	8	22	9	18	13	40	8	0.10	NS	NS	0.01
Bell Island	44	12	28	21	37	18	23	26	NS	NS	NS	NS
Rideau Marina	130	20	21	24	-	51	-	-	0.01	NS	-	-
Elliot Ave.	72	15	42	14	14	22	22	22	0.05	NS	NS	NS
Kingston Mills	40	15	27	22	-	-	-	-	NS	NS	-	-

Note: Wet data includes all samples collected on a rainfall day or one day after rainfall.

* t-test probability levels given.

NS = not significant (P>0.10)

TABLE 5

GEOMETRIC MEANS* OF FECAL COLIFORMS AT KINGSTON BEACHES AND OTHER HEALTH UNIT SAMPLING LOCATIONS

Location	G.M. Org/100 mL
Richardson Beach	138
Portsmouth (Olympic) Harbour (pier)	113
West St. (boat ramp)	59
Alwington Place	51
Lake Ontario Park (buoys)	46
West Street (sailing club)	43
Lake Ontario Park (breakwater)	37
Orchard St. (rowing club)	31
Elliot Ave.	28
Portsmouth (Olympic) Harbour (breakwater)	25
Collingwood St. (wind surfing)	25
Bell Island	24

All Health Unit locations are shown on Figure 1A.

* Based on data collected by the local Health Unit on: July 18, 22, 25, 26, August 6, 22, 1985.

Note: Since the Health Unit sampling frequency varied greatly from station to station (from 5 to 25 sampling dates) it was only possible to carry a station cross-comparison (ranking) based a maximum of 5 - 6 common dates. The reported geometric means are used here for comparison purposes only and do not represent reliable estimates of average summer fecal coliform levels at a station.

TABLE 6

FECAL COLIFORM STATUS AT KINGSTON BEACHES
AND OTHER HEALTH UNIT SAMPLING LOCATIONS
(July 16 - August 30, 1985)

Location	G.M.* Org/100 mL	Percentage of daily 5-sample G.M. Exceeding PWQO
Richardson Beach	83	40
Collingwood St. (wind surfing)	55	38
Lake Ontario Park (buoys)	52	32
West St. Sailing Club	43	23
Alwington Place	38	15
Lake Ontario Park (breakwater)	28	13
Bell Island	24	17

All Health Unit locations are shown on Figure 1A.
* Based on common sampling dates (other data not used).

Note: This data set includes only stations which were sampled by the local Health Unit at least 17 times during July 16 - August 30, and therefore represents a good estimate of average fecal coliform levels at the above stations for that time period.

TABLE 7

(FC/FS) Ratios in Warm-Blooded Animal Feces

Fecal Source	Ratio (FC/FS)	Group Number
Human	20^+	-
Gull	10^+ to 20^+	I
Duck	10^+ to 20^+	I
Dog	10^+ to 20^+	I
Pigeons		II
Muskrat	About 1	II
Chicken	to	II
Pig	Less Than 5	II
Cat		II
Goose		III
Racoon	Less Than 0.5	III
Cow		III

Source: MOE-Sponsored Research Study - Preliminary Results cited in Humber River Bacteriological Study, Technical Report #6 (TAWMS, 1985).

TABLE 8

(FC/FS) RATIOS, KINGSTON SEWERS,
1985 DRY WEATHER SURVEYS

Station #	FC/FS Ratio				
	July 22	July 23	July 24	July 25	August 8
05-71	-	-	-	-	0.25
05-47	-	0.08	-	0.06	-
05-48	-	0.42	-	0.04	0.37
05-49	-	-	-	9.0	0.48
07-01	-	2.2	-	8.8	1.1
05-53	-	1.9	-	-	-
05-55	-	-	-	3.0	7.4
05-58	-	1.3	-	5.8	-
07-05	0.14	0.53	-	0.52	0.49
05-60	3.0	-	10.8	7.0	-
05-61	-	-	0.24	-	-
07-07	13.7	2.1	-	-	11.6
07-09	2.4	6.5	125.0	18.0	34.6
05-72	2.2	-	4.8	-	-
07-10	2.3	-	9.3	-	1.4
05-63	-	-	5.0	-	0.52
05-64	1.04	-	1.9	-	2.0
07-11	8.3	-	-	-	0.5
05-66	-	-	1.8	-	3.4
05-67	1.6	-	3.0	-	-
05-69	4.1	-	9.5	-	103.0

Note: Ratios are based on single sample results (July 24, 25) or on 2-sample geometric means July 22, 23, August 8).

<u>TABLE 9</u>

ENUMERATION OF INDICATOR BACTERIA IN HUMAN AND ANIMAL FECES (MOE, 1986)

Fecal Source	Target Organism (number of bacteria per gram)		
	<u>*Clostridium perfringens*</u>	Fecal Coliform	Fecal Streptococci
Dog	1.4×10^5 * 1.5×10^6 +	2.7×10^7 9.3×10^6	8.2×10^8 1.0×10^8
Cat	9.4×10^5 * 2.2×10^6 +	5.3×10^6 4.3×10^5	2.1×10^7 1.9×10^7
Sheep	1.6×10^3 * 5.3×10^3 +	2.2×10^6 2.7×10^6	5.6×10^6 4.7×10^6
Chicken	5.8×10^2 * 5.1×10^2 +	9.3×10^5 1.1×10^6	3.5×10^6 3.0×10^6
Pig	1.3×10^4 * 1.0×10^4 +	3.2×10^6 5.7×10^6	6.4×10^7 G 1×10^6
Human	L 140 * L 140 *	G 1×10^6 G 1×10^6	G 1×10^6 G 1×10^6

* Overlay + Biobag L = less than G = greater than

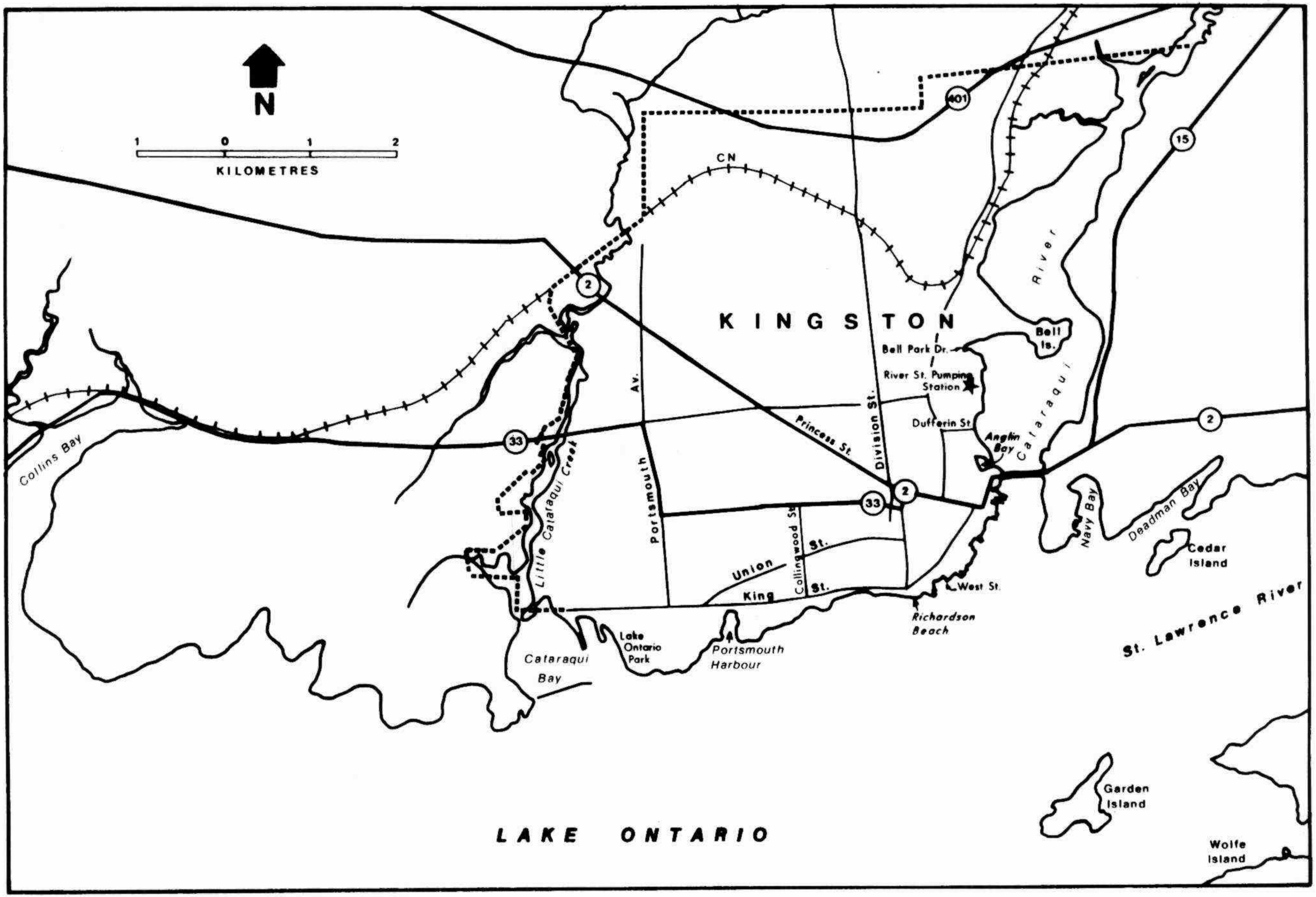

FIGURE 1 : ORIENTATION MAP OF THE KINGSTON AREA

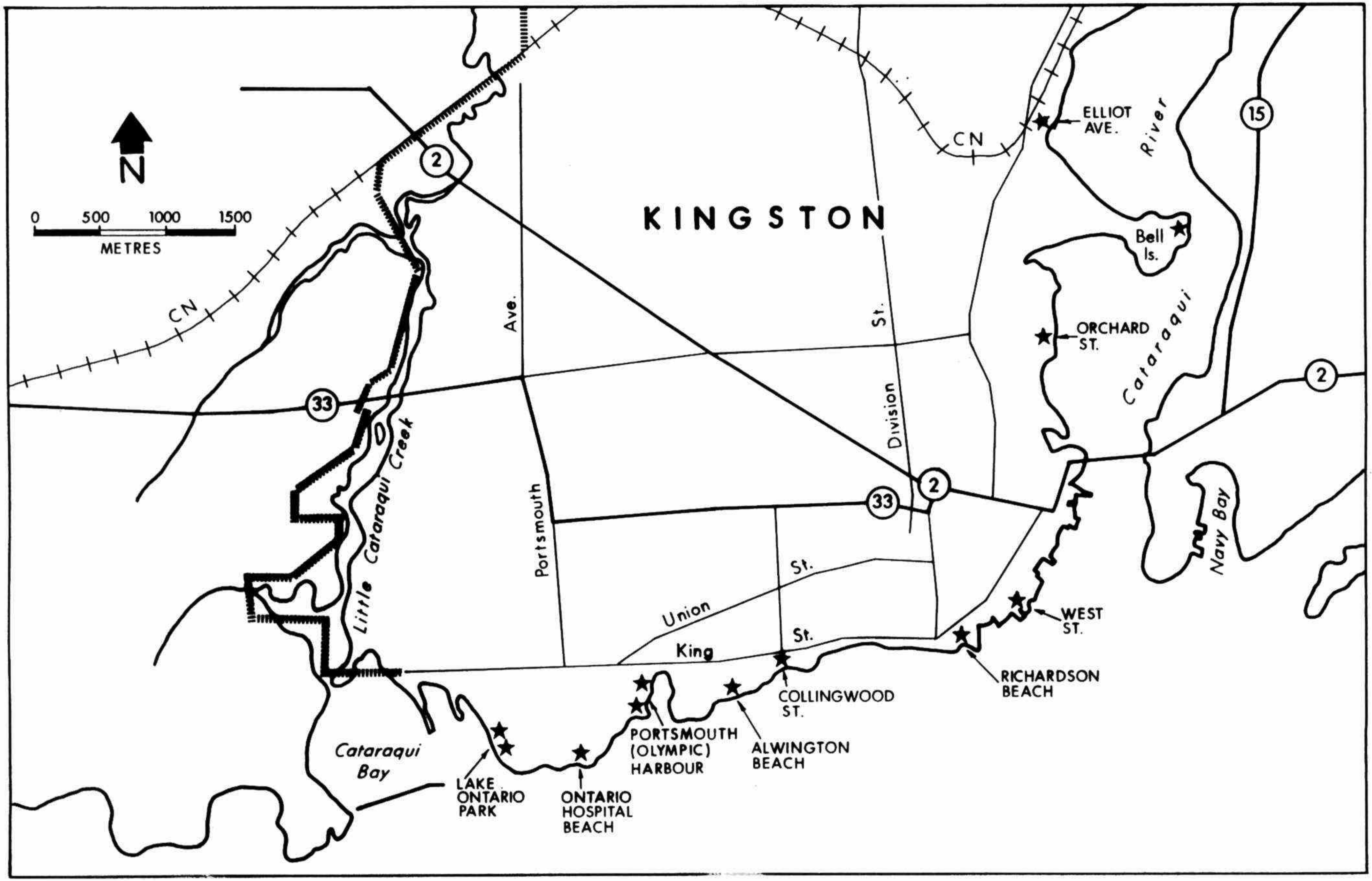

FIGURE 1A: BEACHES SAMPLED BY K,F,L & A HEALTH UNIT

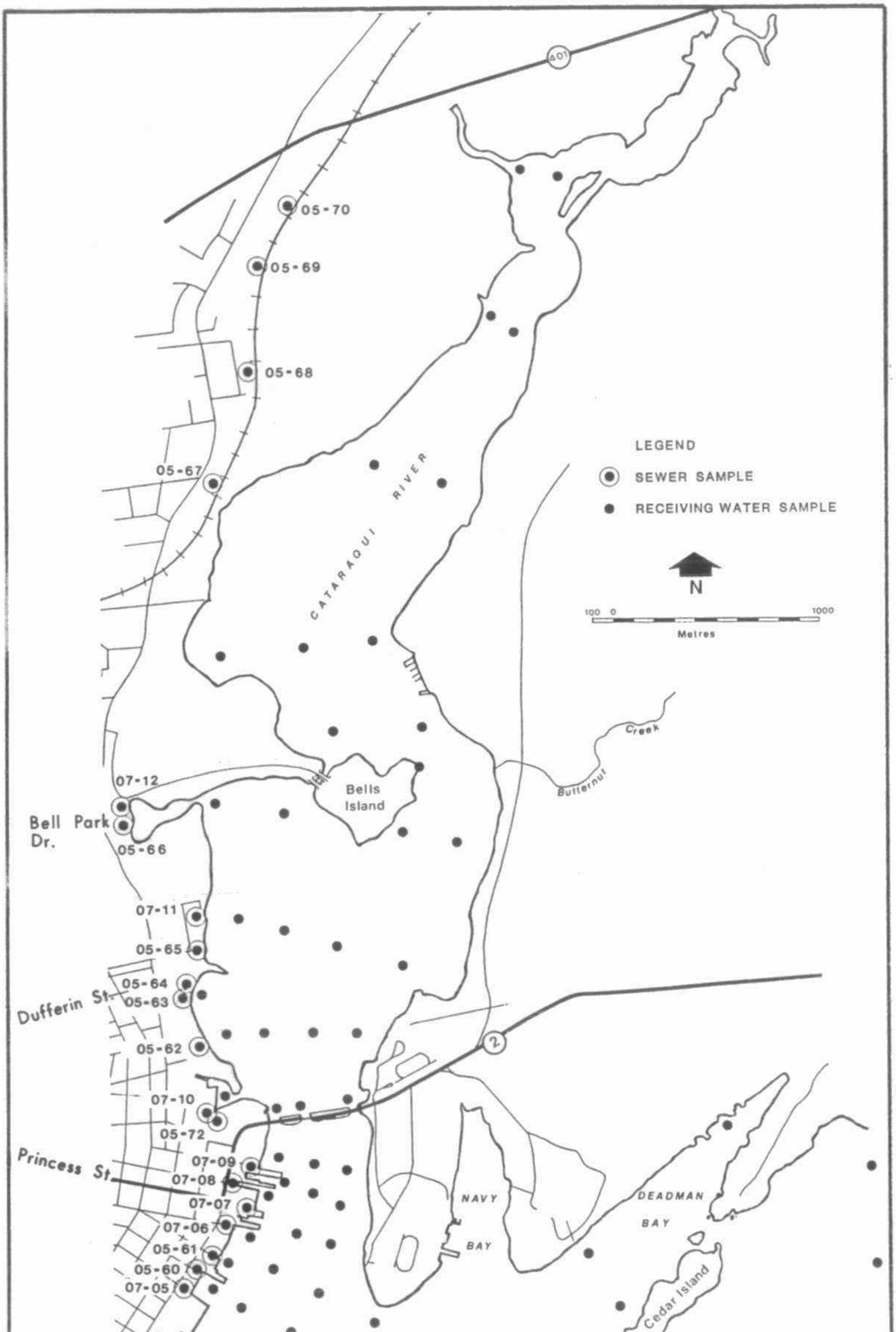

FIGURE 2 : 1985 KINGSTON HARBOUR BACTERIOLOGICAL SURVEY: SUBGRID 1- SAMPLING LOCATIONS

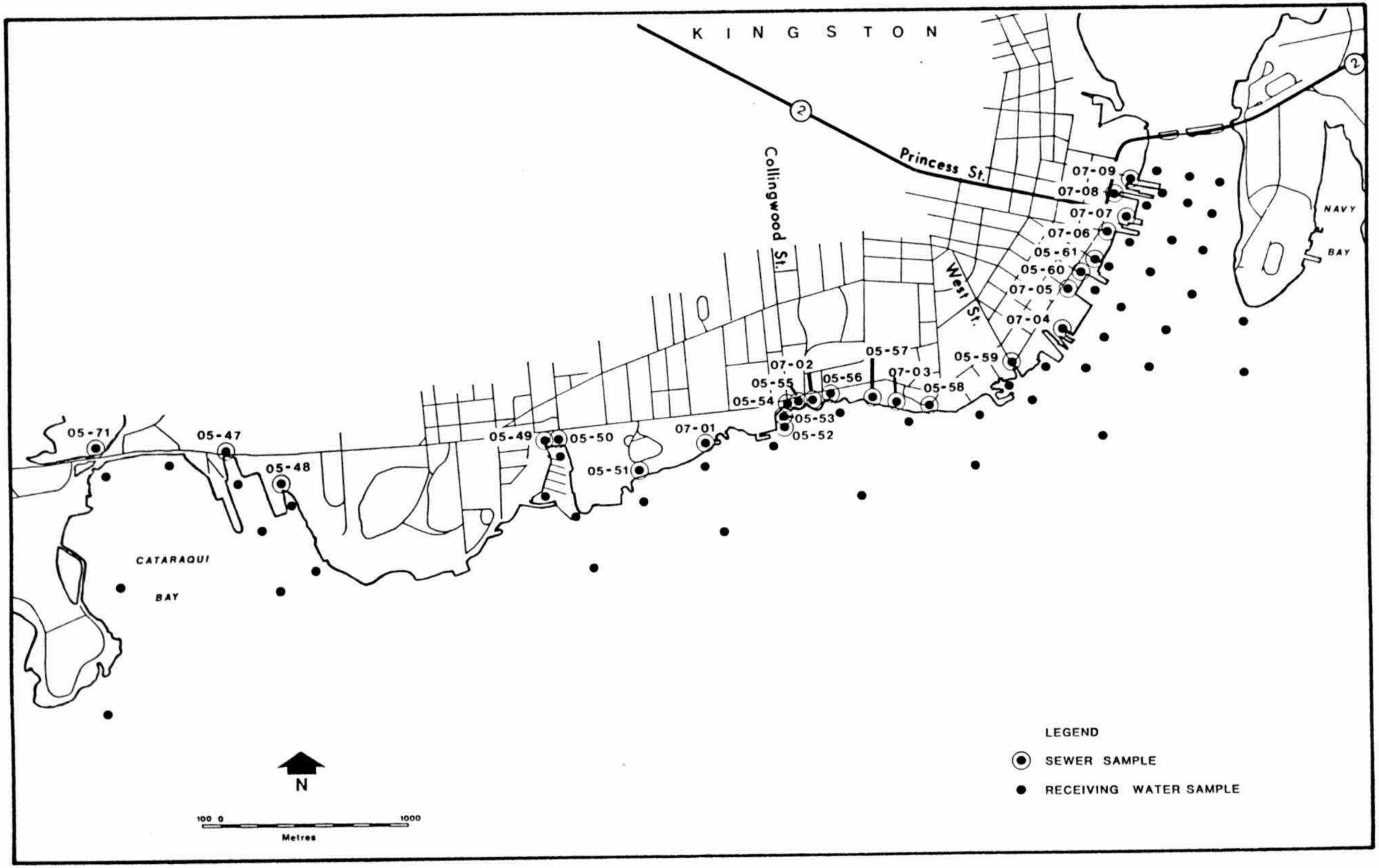

FIGURE 3 : 1985 KINGSTON HARBOUR BACTERIOLOGICAL SURVEY: SUBGRID 2– SAMPLING LOCATIONS

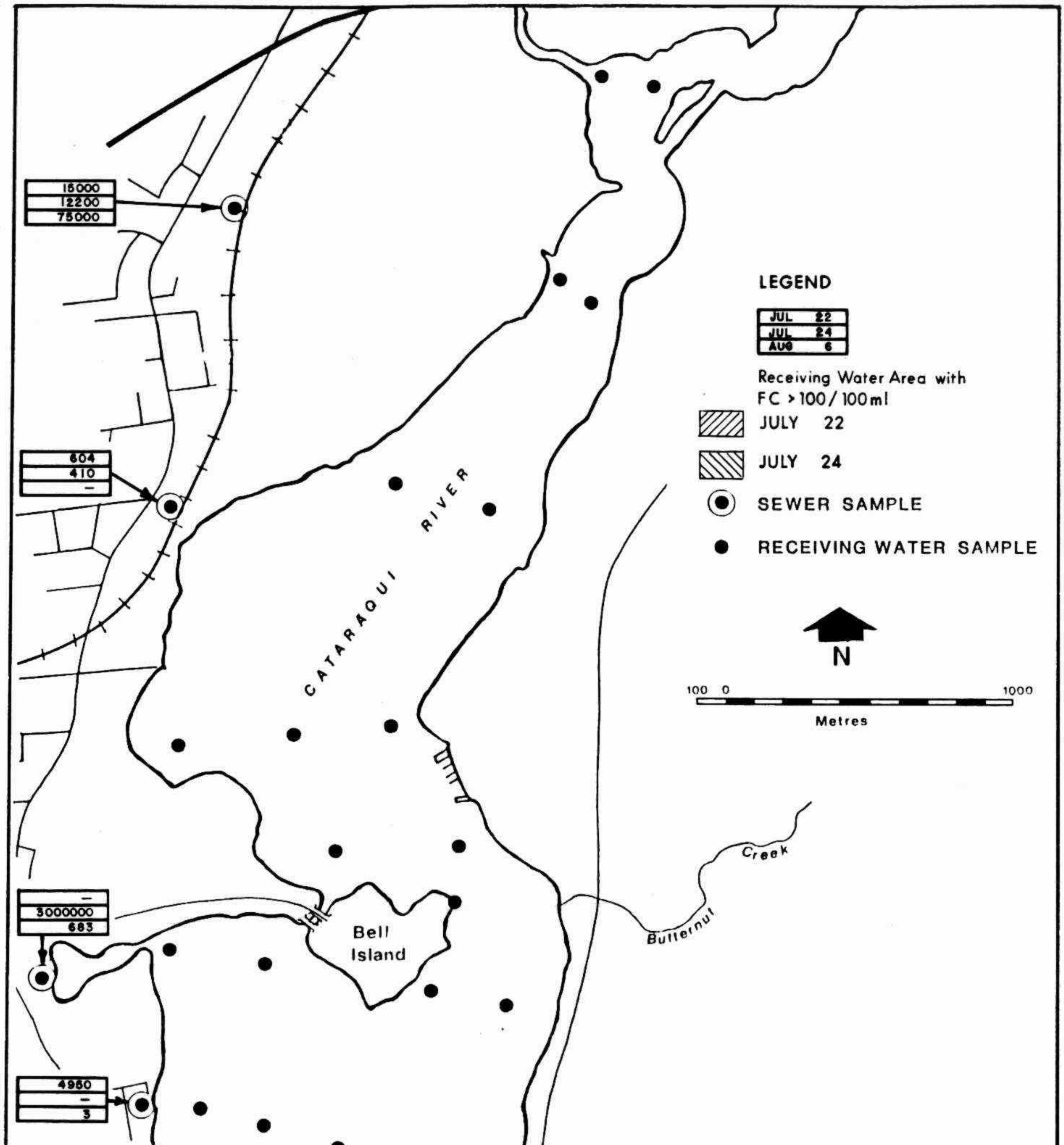

FIGURE 4: FECAL COLIFORM COUNTS (#/100ml) OBSERVED DURING DRY WEATHER, KINGSTON INNER HARBOUR, 1985

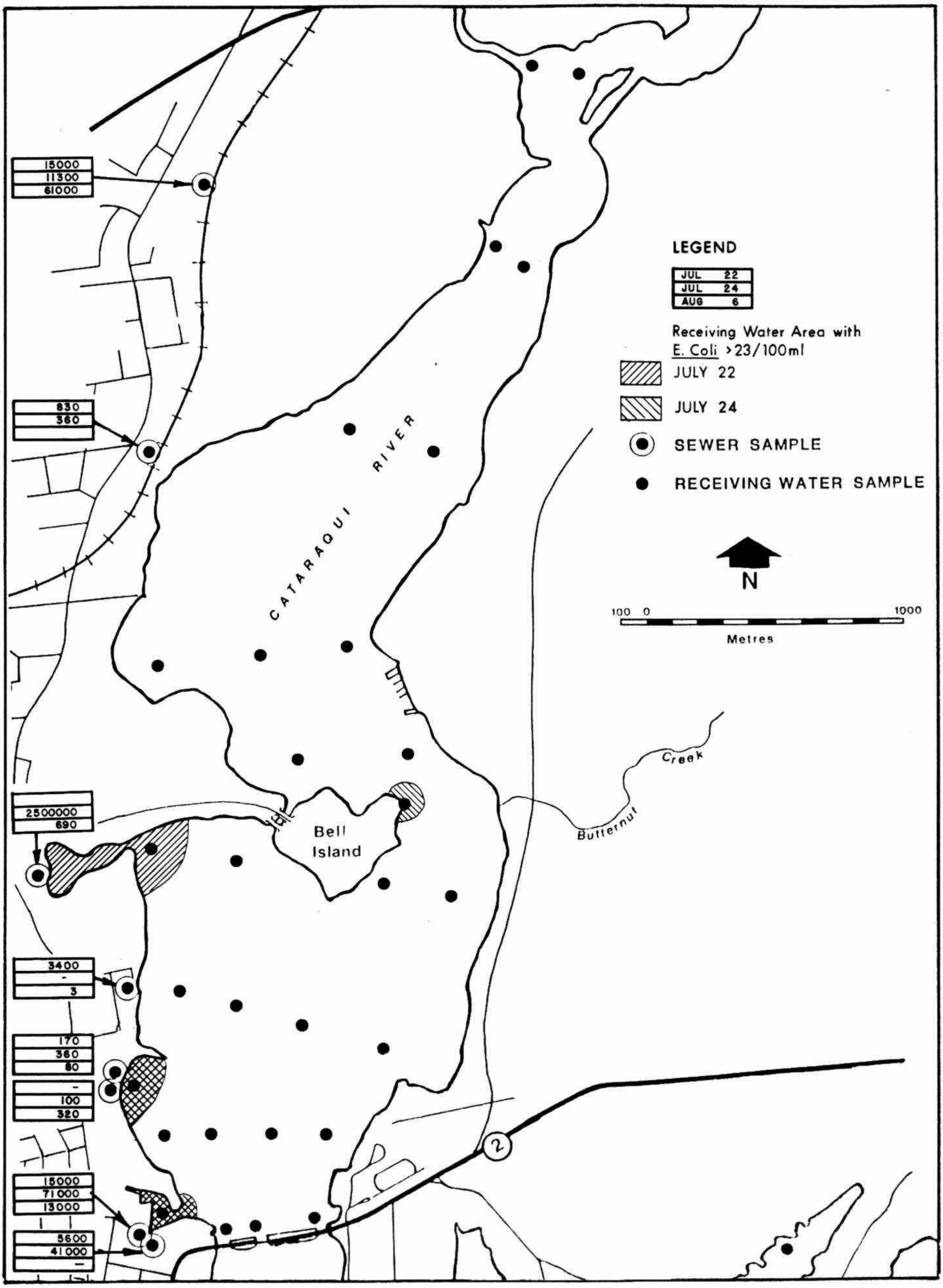

FIGURE 5: E. COLI COUNTS (#/100ml) OBSERVED DURING DRY WEATHER KINGSTON INNER HARBOUR, 1985

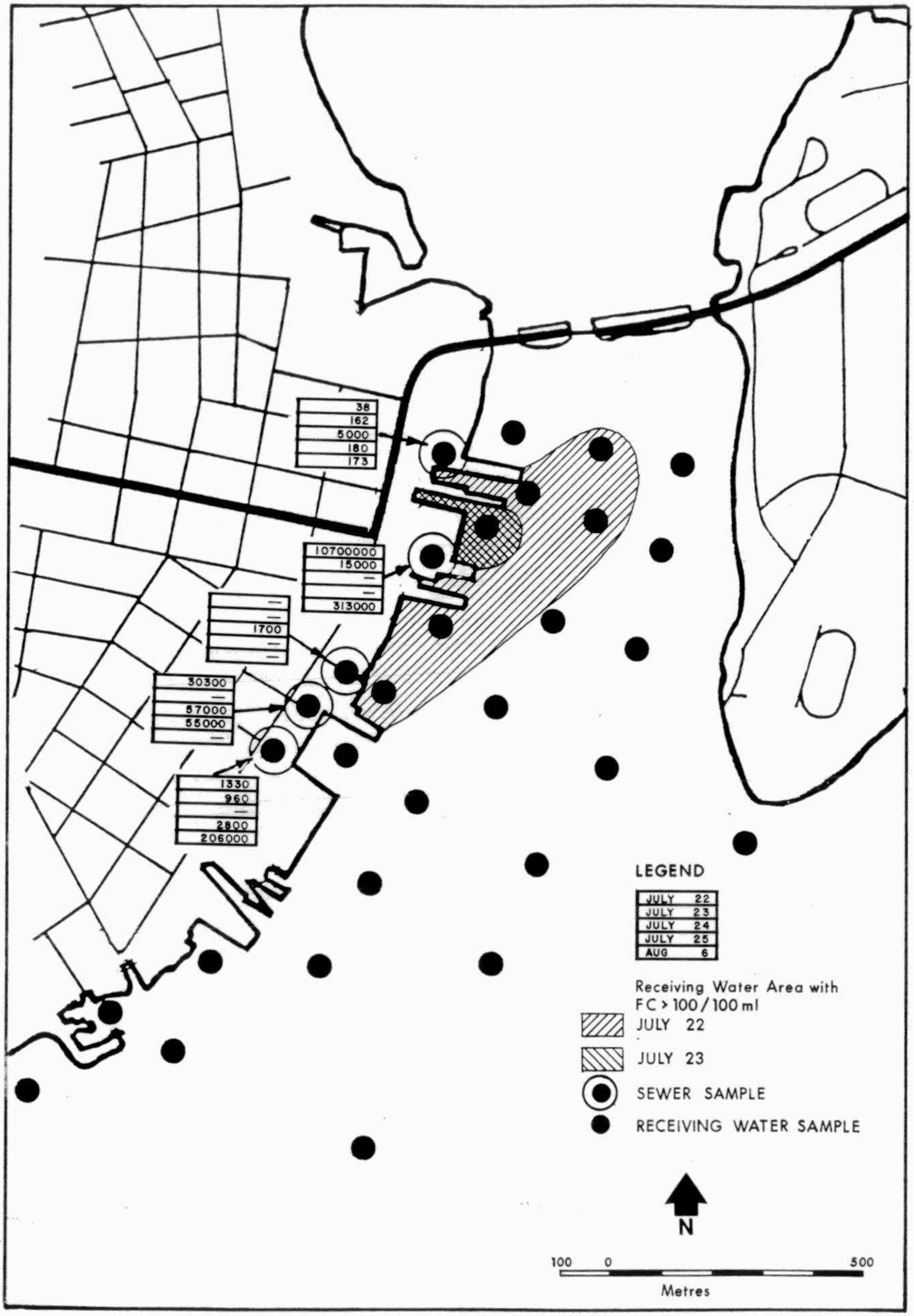

FIGURE 6: FECAL COLIFORM COUNTS (#/100ml) OBSERVED DURING DRY WEATHER DOWNTOWN KINGSTON WATERFRONT, 1985

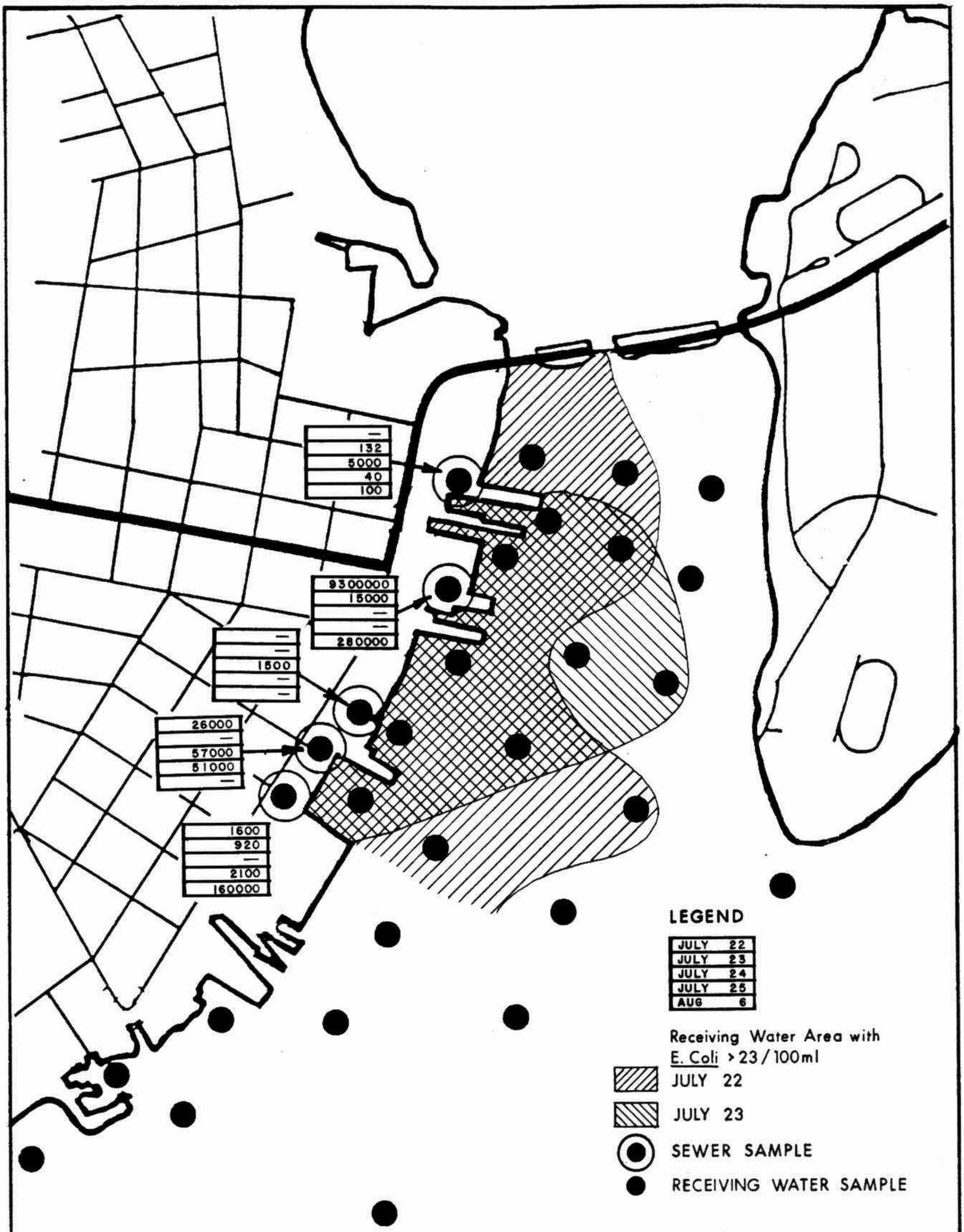

FIGURE 7: E. COLI COUNTS (#/100ml)
OBSERVED DURING DRY WEATHER
DOWNTOWN KINGSTON WATERFRONT, 1985

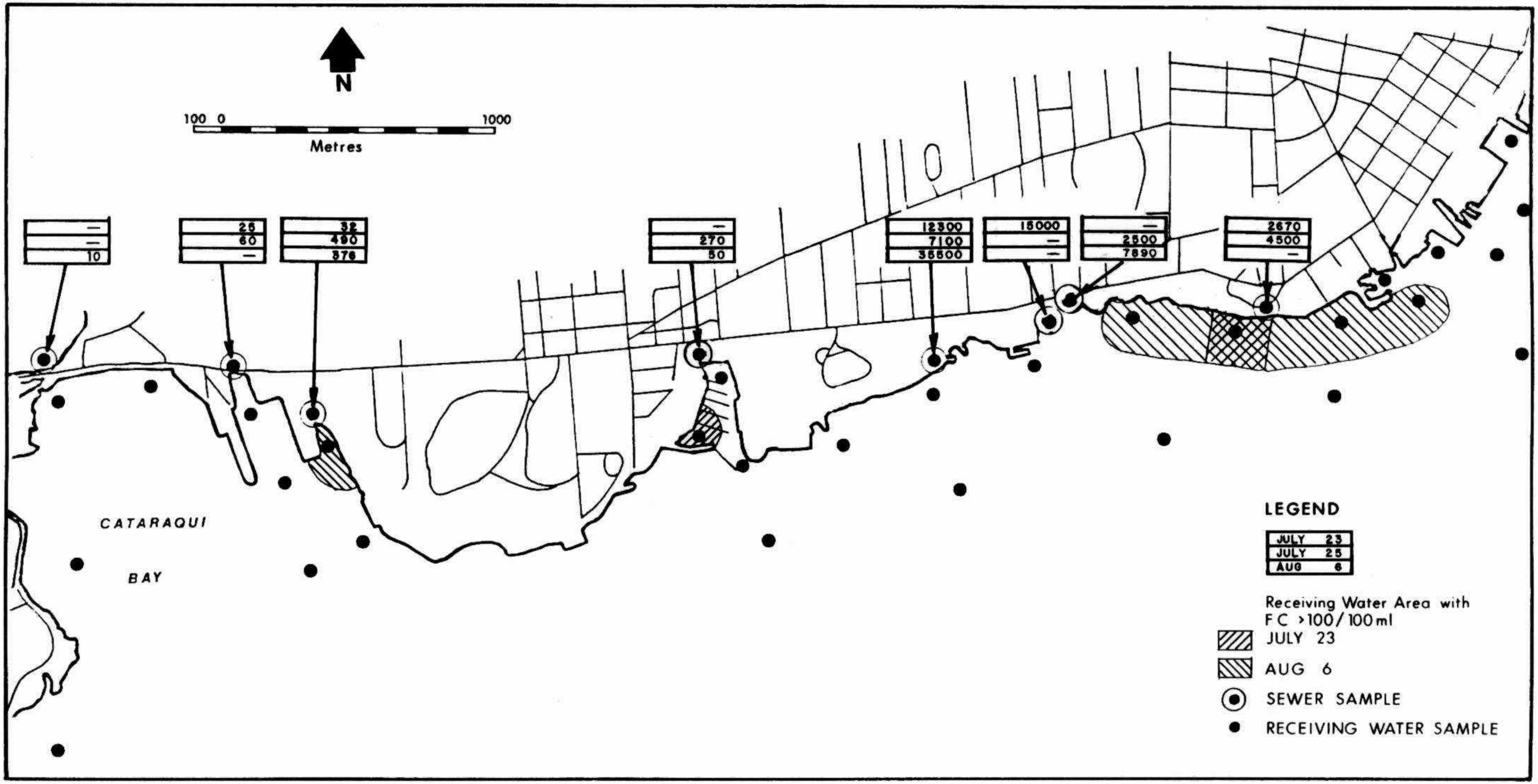

FIGURE 8: FECAL COLIFORM COUNTS (#/100ml) OBSERVED DURING DRY WEATHER, LAKE ONTARIO WATERFRONT AT KINGSTON, 1985

FIGURE 9: E. COLI COUNTS (#/100ml)
OBSERVED DURING DRY WEATHER,
LAKE ONTARIO WATERFRONT AT KINGSTON, 1985

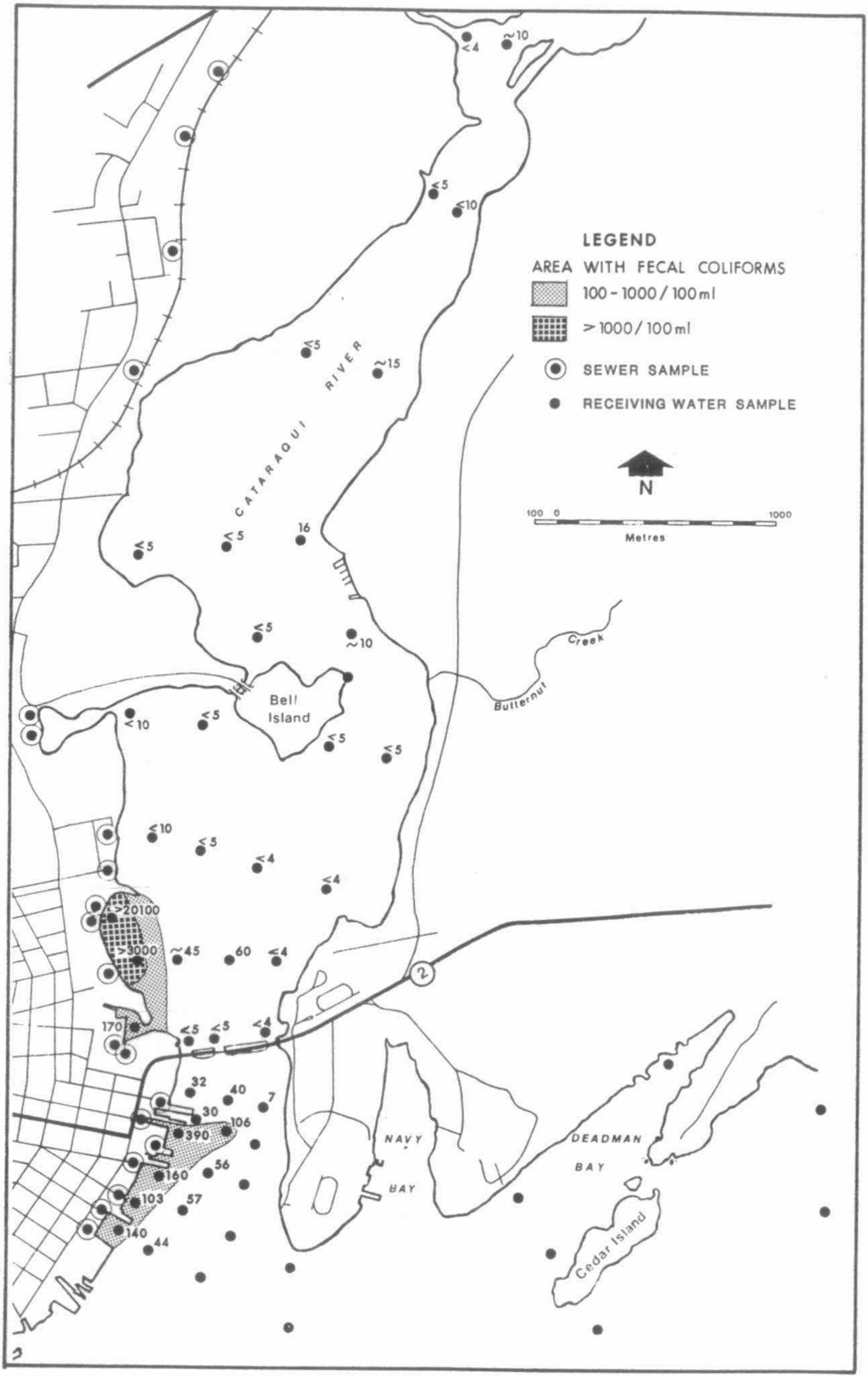

FIGURE 10: KINGSTON subgrid 1 FECAL COLIFORM LEVELS (org./100ml) AUGUST 8, 1985

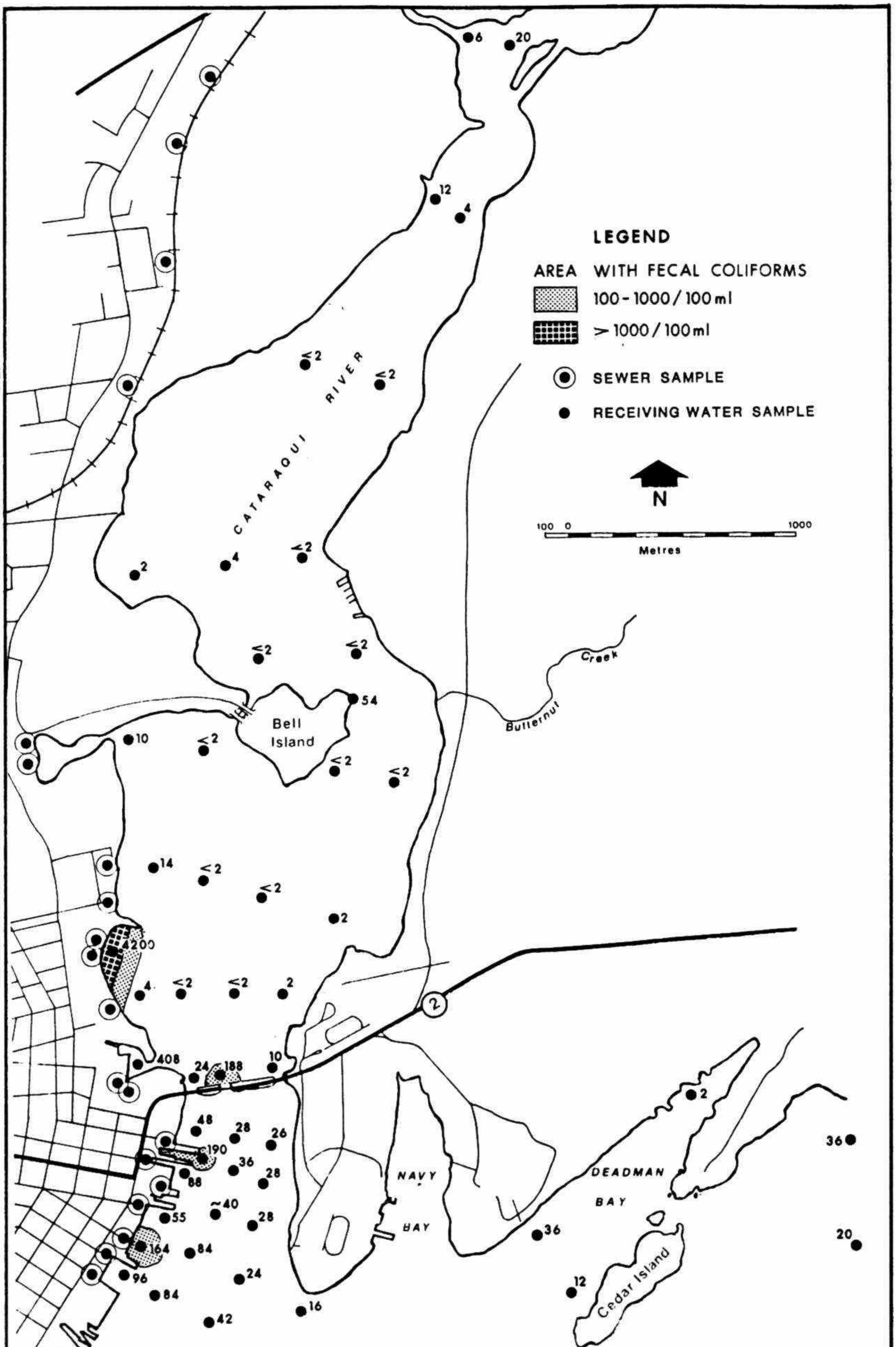

FIGURE 11: KINGSTON subgrid 1 FECAL COLIFORM LEVELS (org/100ml)
AUGUST 14, 1985

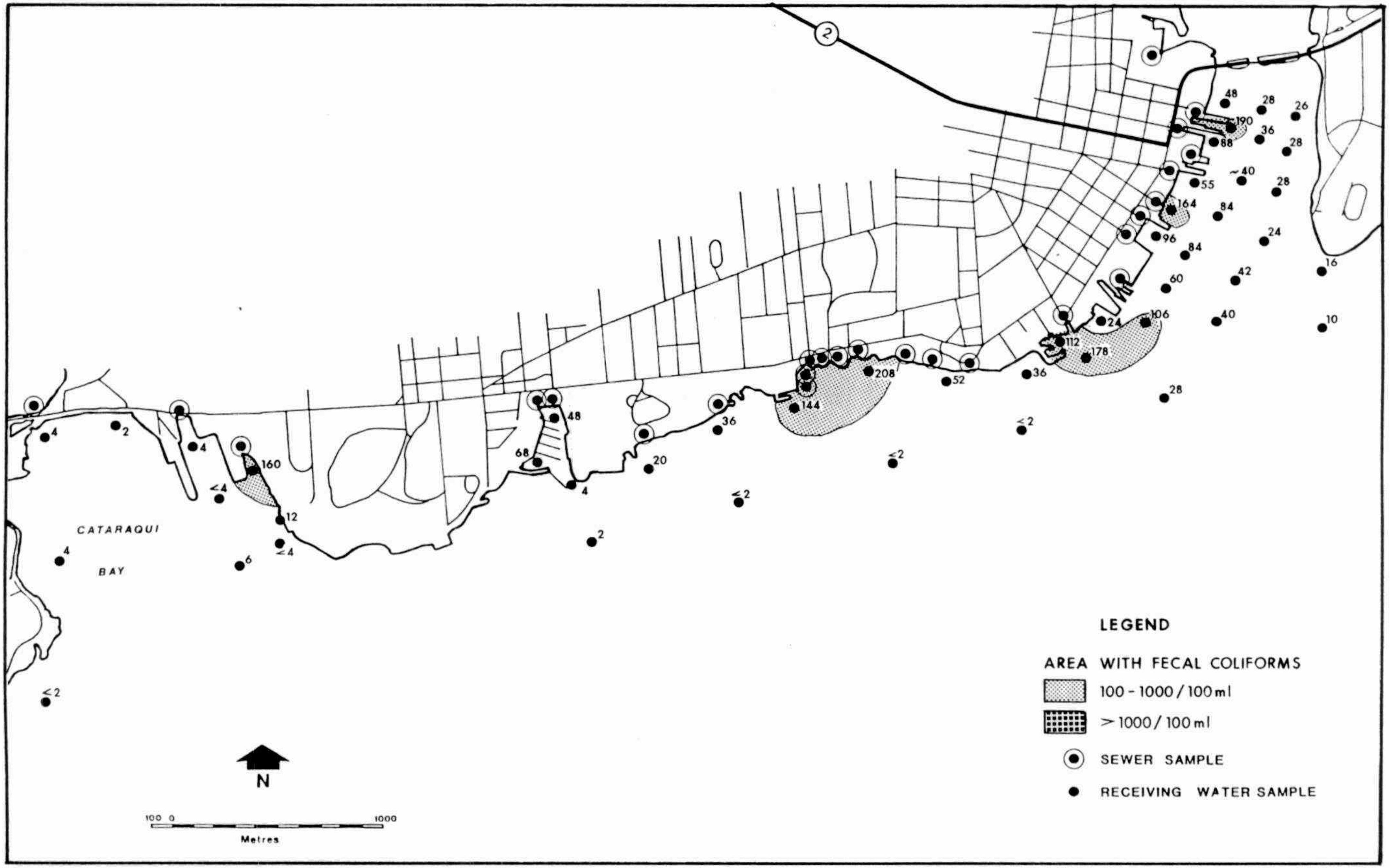

FIGURE 12: KINGSTON subgrid 2 FECAL COLIFORM LEVELS (org/100ml) AUGUST 14, 1985

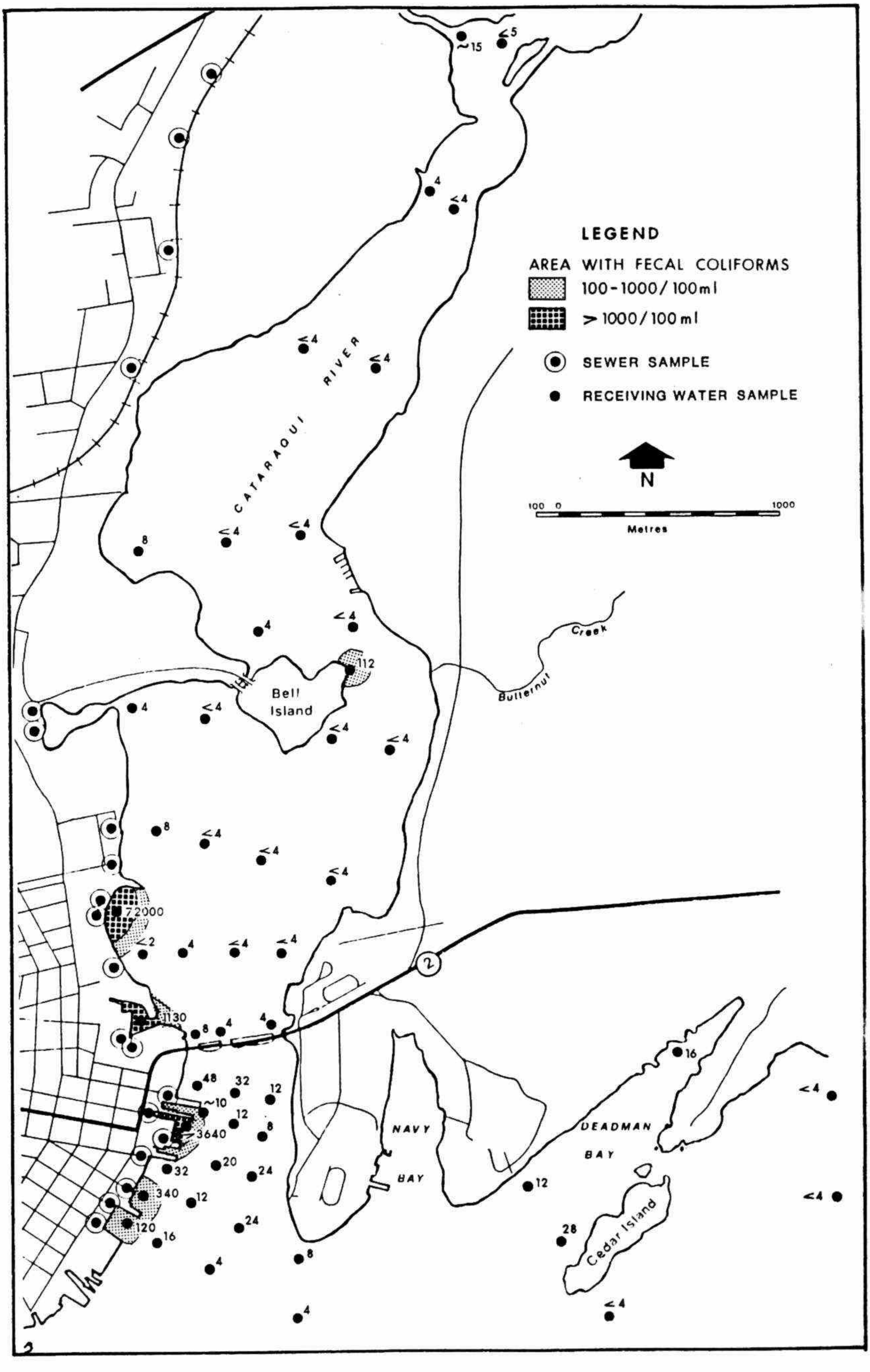

FIGURE 13: KINGSTON subgrid 1 FECAL COLIFORM LEVELS (org/100ml)
AUGUST 15, 1985

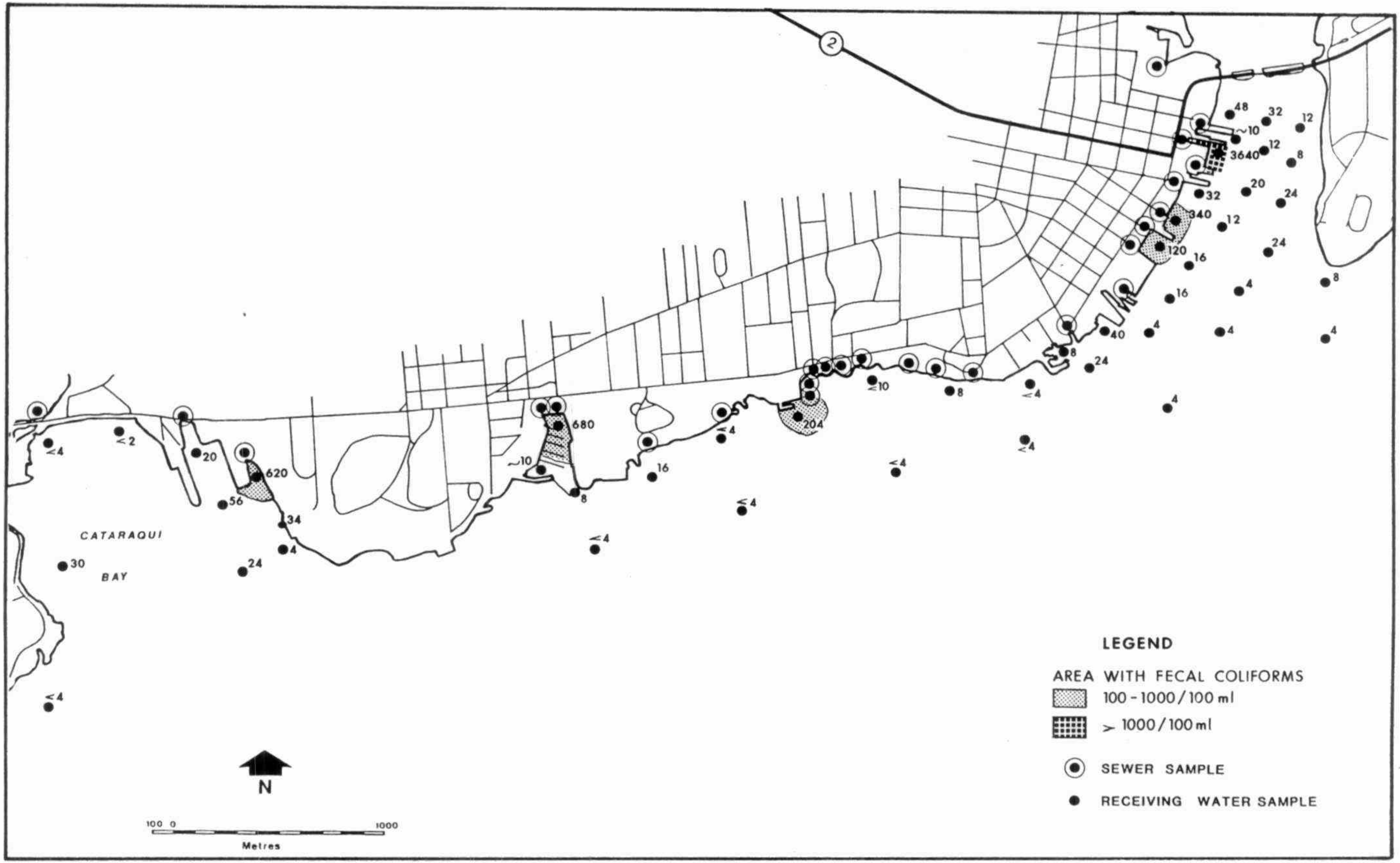

FIGURE 14: KINGSTON subgrid 2 FECAL COLIFORM LEVELS (org/100ml) AUGUST 15, 1985

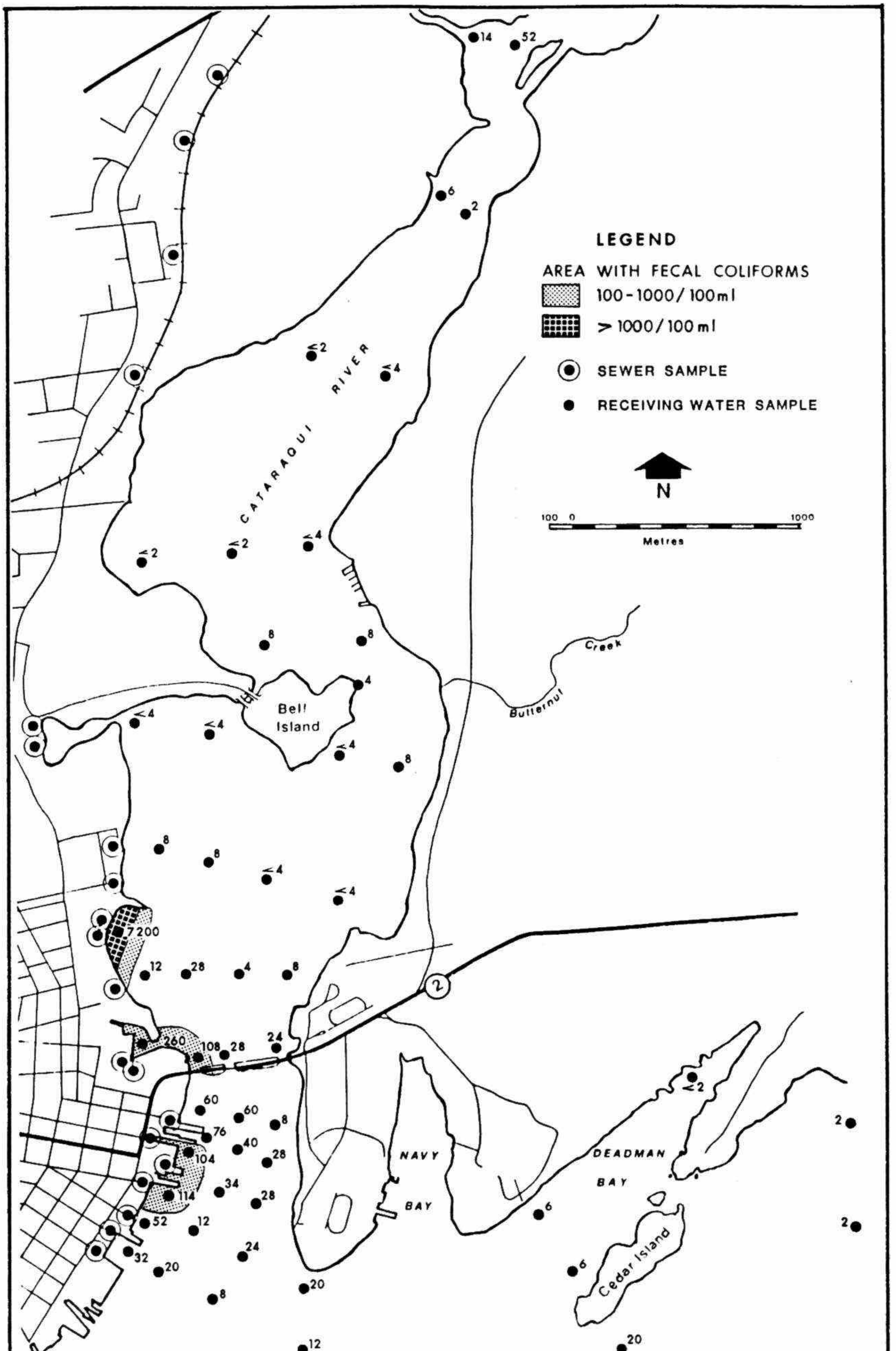

FIGURE 15: KINGSTON subgrid 1 FECAL COLIFORM LEVELS (org/100ml) AUGUST 16, 1985

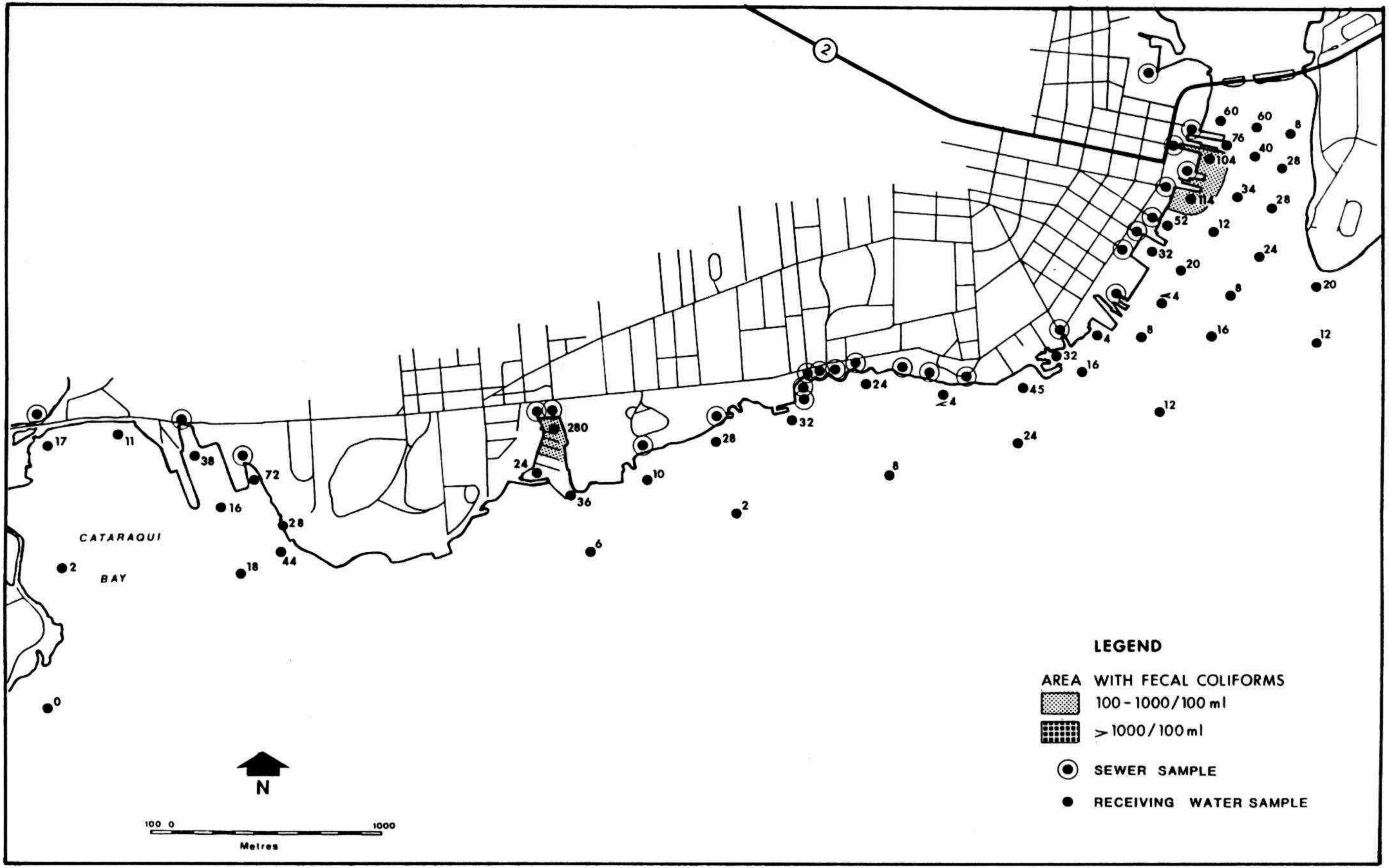

FIGURE 16: KINGSTON subgrid 2 FECAL COLIFORM LEVELS (org/100ml) AUGUST 16, 1985

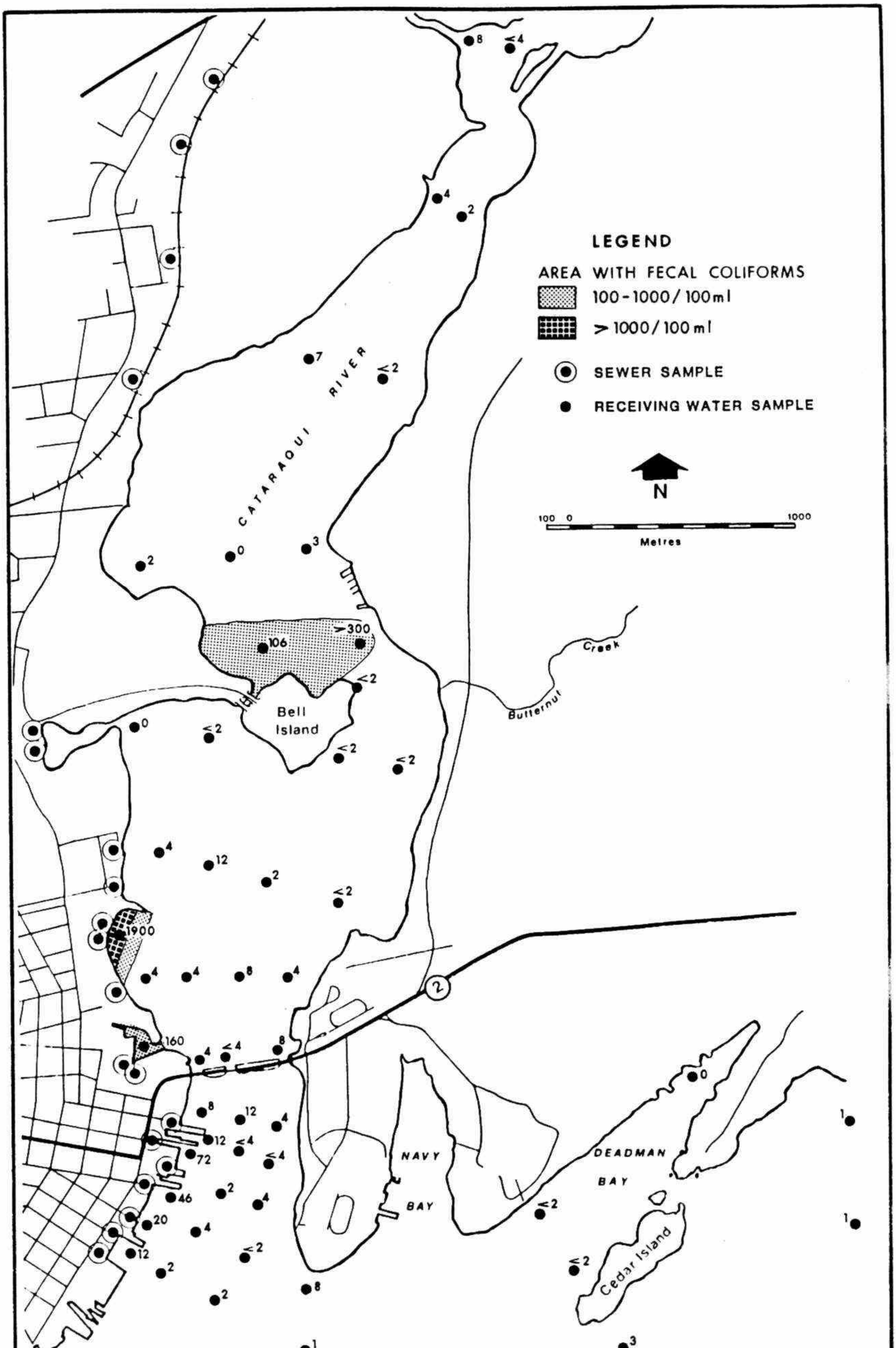

FIGURE 17: KINGSTON subgrid 1 FECAL COLIFORM LEVELS (org/100ml)
AUGUST 17, 1985